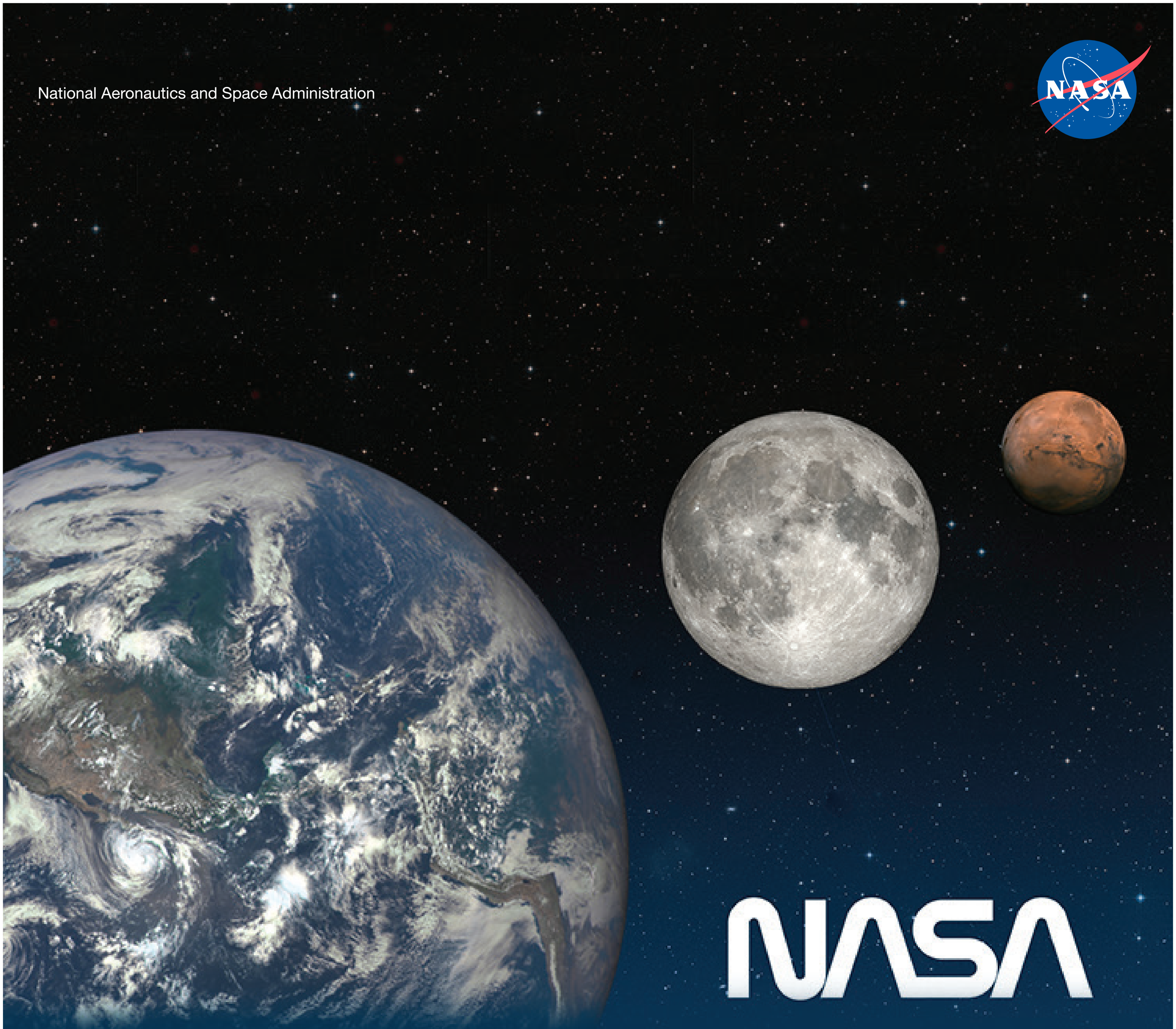
National Aeronautics and Space Administration



FY 2023 Budget Estimates

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National Aeronautics and Space Administration

FY 2023 PRESIDENT'S BUDGET REQUEST SUMMARY

Budget Authority ($ in millions)	Op Plan 2021	Request 2022	Request 2023	2024	2025	2026	2027
				Fiscal Year			
NASA Total	23,271.3	24,801.5	25,973.8	26,493.4	27,023.3	27,563.7	28,114.8
Deep Space Exploration Systems	6,396.5	6,750.2	7,478.3	6,798.1	6,813.4	6,912.3	7,040.8
Common Exploration Systems Development	4,538.7	4,483.7	4,668.4	3,613.8	3,111.9	2,845.6	2,376.8
Artemis Campaign Development	1,672.1	2,062.0	2,600.3	2,973.8	3,489.3	3,853.9	4,450.7
Human Exp Requirements & Architecture	9.5	9.5	48.3	48.9	49.5	50.0	50.5
Mars Campaign Development	176.2	195.0	161.3	161.6	162.7	162.7	162.8
Space Operations	4,101.9	4,147.6	4,266.3	5,181.4	5,405.6	5,551.1	5,671.8
International Space Station	1,321.6	1,327.6	1,307.5	1,289.9	1,302.1	1,302.5	1,302.9
Space Transportation	1,871.9	1,770.2	1,759.5	1,798.8	1,848.7	1,889.2	1,914.8
Space and Flight Support (SFS)	890.3	947.2	975.0	1,031.7	1,053.1	1,020.1	948.6
Commercial LEO Development	18.1	102.6	224.3	228.2	229.4	302.1	435.0
Exploration Operations	--	--	TBD	832.9	972.3	1,037.2	1,070.5
Space Technology	1,100.0	1,425.0	1,437.9	1,466.7	1,496.0	1,525.9	1,556.4
Science	7,290.7	7,931.4	7,988.3	8,148.1	8,311.1	8,477.3	8,646.8
Earth Science	1,996.5	2,250.0	2,411.5	2,460.3	2,589.0	2,722.3	2,782.0
Planetary Science	2,693.2	3,200.0	3,160.2	3,186.1	3,197.4	3,176.4	3,299.0
Astrophysics	1,770.9	1,575.2	1,556.0	1,597.0	1,578.5	1,620.5	1,625.6
Heliophysics	751.0	797.2	760.2	802.6	842.0	851.9	831.9
Biological and Physical Sciences	79.1	109.1	100.4	102.1	104.1	106.2	108.4
Aeronautics	828.7	914.8	971.5	990.9	1,010.7	1,030.9	1,051.5
STEM Engagement	127.0	147.0	150.1	153.1	156.2	159.3	162.5
Safety, Security, and Mission Services	2,936.5	3,049.2	3,208.7	3,272.9	3,338.4	3,405.2	3,473.3
Mission Services & Capabilities	1,918.3	2,028.8	2,154.4	2,197.5	2,241.5	2,286.3	2,332.0
Engineering, Safety, & Operations	1,018.2	1,020.4	1,054.3	1,075.4	1,096.9	1,118.9	1,141.3
Construction and Environmental Compliance and Restoration	445.8	390.3	424.3	432.8	441.5	450.3	459.3
Construction of Facilities	387.7	315.6	348.1	353.4	360.5	367.6	376.6
Environmental Compliance and Restoration	58.1	74.7	76.2	79.4	81.0	82.7	82.7
Inspector General	44.2	46.0	48.4	49.4	50.4	51.4	52.4
NASA Total	23,271.3	24,801.5	25,973.8	26,493.4	27,023.3	27,563.7	28,114.8

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

FY 2023 President's Budget Request Summary

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The FY 2023 President's budget request for NASA includes authority to transfer funds in FY 2023 from Orion Multi-purpose Crew Vehicle to Exploration Operations for Orion Production and Operations, up to $718 million, contingent on assessments following Artemis I.

FY 2023 PRESIDENT'S BUDGET REQUEST SUMMARY

Budget Authority ($ in millions)	Op Plan 2021	Request 2022	Request 2023	2024	2025	2026	2027
NASA Total	**23,271.3**	**24,801.5**	**25,973.8**	**26,493.4**	**27,023.3**	**27,563.7**	**28,114.8**
Deep Space Exploration Systems	**6,396.5**	**6,750.2**	**7,478.3**	**6,798.1**	**6,813.4**	**6,912.3**	**7,040.8**
Common Exploration Systems Development	**4,538.7**	**4,483.7**	**4,668.4**	**3,613.8**	**3,111.9**	**2,845.6**	**2,376.8**
Orion Program	**1,403.7**	**1,406.7**	**1,338.7**	**415.0**	**116.5**	**52.0**	**19.0**
Crew Vehicle Development	1,387.8	1,388.8	1,325.3	415.0	116.5	52.0	19.0
Orion Program Integration and Support	15.9	17.9	13.4	--	--	--	--
Space Launch System	**2,555.0**	**2,487.0**	**2,579.8**	**2,534.6**	**2,484.6**	**2,326.5**	**1,925.5**
Launch Vehicle Development	2,488.4	2,414.0	2,505.7	2,455.8	2,393.2	2,234.4	1,832.7
SLS Program Integration and Support	66.6	73.0	74.0	78.8	91.3	92.0	92.7
Exploration Ground Systems	**580.0**	**590.0**	**749.9**	**664.2**	**510.8**	**467.2**	**432.3**
Exploration Ground Systems Development	569.2	585.3	747.3	660.0	503.8	460.0	425.0
EGS Program Integration and Support	10.8	4.7	2.6	4.2	7.0	7.2	7.3
Artemis Campaign Development	**1,672.1**	**2,062.0**	**2,600.3**	**2,973.8**	**3,489.3**	**3,853.9**	**4,450.7**
Gateway	**501.5**	**685.0**	**779.2**	**754.5**	**685.4**	**661.7**	**758.2**
Adv Cislunar and Surface Capabilities	**45.0**	**82.0**	**59.6**	**57.8**	**62.9**	**425.2**	**555.6**
Human Landing System	**928.3**	**1,195.0**	**1,485.6**	**1,863.8**	**2,246.1**	**2,168.2**	**2,537.9**
xEVA and Human Surface Mobility Program	**197.3**	**100.0**	**275.9**	**297.7**	**494.9**	**598.8**	**599.1**
Human Exp Requirements & Architecture	**9.5**	**9.5**	**48.3**	**48.9**	**49.5**	**50.0**	**50.5**
Moon & Mars Architecture	**9.5**	**9.5**	**48.3**	**48.9**	**49.5**	**50.0**	**50.5**
Mars Campaign Development	**176.2**	**195.0**	**161.3**	**161.6**	**162.7**	**162.7**	**162.8**
Exploration Capabilities	**176.2**	**195.0**	**161.3**	**161.6**	**162.7**	**162.7**	**162.8**
Space Operations	**4,101.9**	**4,147.6**	**4,266.3**	**5,181.4**	**5,405.6**	**5,551.1**	**5,671.8**
International Space Station	**1,321.6**	**1,327.6**	**1,307.5**	**1,289.9**	**1,302.1**	**1,302.5**	**1,302.9**
International Space Station Program	**1,321.6**	**1,327.6**	**1,307.5**	**1,289.9**	**1,302.1**	**1,302.5**	**1,302.9**
ISS Systems Operations and Maintenance	1,013.8	1,048.2	1,041.7	1,024.0	1,031.1	1,031.5	1,031.9
ISS Research	307.8	279.4	265.8	265.9	271.0	271.0	271.0
Space Transportation	**1,871.9**	**1,770.2**	**1,759.5**	**1,798.8**	**1,848.7**	**1,889.2**	**1,914.8**
Crew and Cargo Program	**1,573.2**	**1,617.2**	**1,642.0**	**1,698.8**	**1,748.7**	**1,789.2**	**1,814.8**
Commercial Crew Program	**298.7**	**153.0**	**117.5**	**100.0**	**100.0**	**100.0**	**100.0**
Space and Flight Support (SFS)	**890.3**	**947.2**	**975.0**	**1,031.7**	**1,053.1**	**1,020.1**	**948.6**
Space Communications and Navigation	**506.0**	**522.6**	**528.5**	**574.7**	**593.6**	**565.5**	**493.8**
Space Communications Networks	398.3	393.4	415.0	471.5	492.1	465.2	388.0
Space Communications Support	107.7	129.3	113.4	103.2	101.6	100.3	105.8
Human Space Flight Operations	**97.8**	**101.8**	**101.5**	**103.7**	**104.3**	**104.3**	**104.3**
Human Research Program	**115.0**	**130.2**	**151.2**	**151.2**	**152.0**	**147.0**	**147.1**

FY 2023 PRESIDENT'S BUDGET REQUEST SUMMARY

Budget Authority ($ in millions)	Op Plan 2021	Request 2022	Request 2023	2024	2025	2026	2027
Launch Services	**91.9**	**102.7**	**93.9**	**94.3**	**94.8**	**94.8**	**94.9**
Rocket Propulsion Test	**47.6**	**47.8**	**48.2**	**48.5**	**48.7**	**48.8**	**48.8**
Communications Services Program	**23.4**	**42.0**	**51.7**	**59.4**	**59.7**	**59.7**	**59.7**
Commercial LEO Development	**18.1**	**102.6**	**224.3**	**228.2**	**229.4**	**302.1**	**435.0**
Exploration Operations	**--**	**--**	**TBD**	**832.9**	**972.3**	**1,037.2**	**1,070.5**
Orion Production & Sustainment	**--**	**--**	**TBD**	**786.9**	**925.3**	**990.2**	**1,022.5**
Exploration Operations	**--**	**--**	**TBD**	**46.0**	**47.0**	**47.0**	**48.0**
Space Technology	1,100.0	1,425.0	1,437.9	1,466.7	1,496.0	1,525.9	1,556.4
Early Stage Innovation and Partnerships	**117.5**	**145.0**	**155.9**	**159.5**	**162.7**	**169.9**	**188.2**
Agency Technology and Innovation	8.4	9.4	9.6	9.8	10.0	10.0	10.0
Early Stage Innovation	89.2	115.6	125.3	127.6	130.1	137.3	155.6
Technology Transfer	19.9	20.0	21.0	22.1	22.6	22.6	22.6
Technology Maturation	**227.1**	**491.2**	**471.6**	**481.1**	**491.2**	**497.6**	**493.1**
Technology Demonstration	**528.4**	**501.8**	**525.4**	**535.4**	**545.6**	**556.0**	**566.6**
Solar Electric Propulsion (SEP)	26.2	24.2	18.5	15.9	17.8	5.8	3.8
OSAM-1	227.0	227.0	227.0	227.0	121.8	25.4	--
Small Spacecraft, Flight Opportunities & Other Tech Demo	275.2	250.6	279.9	292.5	406.0	524.8	562.8
SBIR and STTR	**227.0**	**287.0**	**285.0**	**290.7**	**296.5**	**302.4**	**308.5**
Science	7,290.7	7,931.4	7,988.3	8,148.1	8,311.1	8,477.3	8,646.8
Earth Science	**1,996.5**	**2,250.0**	**2,411.5**	**2,460.3**	**2,589.0**	**2,722.3**	**2,782.0**
Earth Science Research	**484.3**	**593.5**	**534.9**	**575.6**	**597.5**	**609.6**	**622.1**
Earth Science Research and Analysis	352.5	409.9	368.9	389.6	394.2	402.7	411.0
Computing and Management	131.8	183.6	166.0	186.0	203.3	206.8	211.1
Earth Systematic Missions	**773.1**	**749.8**	**998.1**	**979.3**	**1,061.3**	**1,119.6**	**1,034.5**
Surface Water and Ocean Topography Mission (SWOT)	68.9	27.8	47.5	10.5	10.6	6.5	6.5
NASA-ISRO Synthetic Aperture Radar (NISAR)	90.8	58.0	58.6	29.0	25.0	14.9	16.5
Sentinel-6	8.0	22.8	40.3	63.9	55.2	25.6	8.7
Plankton, Aerosols, Clouds, ocean Ecosystem (PACE)	145.1	81.9	112.8	73.3	20.9	22.3	7.5
Other Missions and Data Analysis	460.4	559.4	739.0	802.7	949.5	1,050.3	995.3
Earth System Explorers	**--**	**6.6**	**23.4**	**36.3**	**92.0**	**150.2**	**251.3**
Earth System Science Pathfinder	**286.8**	**391.0**	**308.4**	**274.8**	**237.5**	**219.3**	**230.4**
Venture Class Missions	200.7	226.4	194.5	146.3	125.7	167.7	181.9
MAIA	17.5	70.0	13.1	26.5	20.2	1.7	0.6
GeoCarb	16.1	39.7	47.6	49.0	43.8	9.4	6.7
Other Missions and Data Analysis	52.5	54.9	53.3	52.9	47.8	40.5	41.2
Earth Science Data Systems	**299.6**	**344.4**	**366.1**	**406.7**	**383.9**	**399.1**	**414.8**
Earth Science Technology	**83.7**	**91.1**	**102.3**	**105.9**	**114.1**	**117.7**	**119.0**
Applied Sciences	**69.0**	**73.5**	**78.2**	**81.8**	**102.8**	**106.7**	**109.9**

FY 2023 PRESIDENT'S BUDGET REQUEST SUMMARY

Budget Authority ($ in millions)	Op Plan 2021	Request 2022	Request 2023	2024	2025	2026	2027
Planetary Science	**2,693.2**	**3,200.0**	**3,160.2**	**3,186.1**	**3,197.4**	**3,176.4**	**3,299.0**
Planetary Science Research	**304.1**	**309.0**	**298.6**	**299.4**	**309.3**	**324.9**	**342.3**
Planetary Science Research and Analysis	223.2	221.3	213.1	216.6	226.3	230.0	219.4
Other Missions and Data Analysis	80.9	87.8	85.5	82.8	83.0	94.8	122.9
Planetary Defense	**158.1**	**202.1**	**87.7**	**116.5**	**181.5**	**242.5**	**247.7**
NEO Surveyor	31.3	143.2	39.9	75.0	140.0	200.0	200.0
Other Missions and Data Analysis	126.8	58.9	47.8	41.5	41.5	42.5	47.7
Lunar Discovery and Exploration	**443.5**	**497.3**	**486.3**	**458.3**	**458.3**	**458.3**	**468.3**
VIPER	99.1	112.2	97.0	30.6	--	--	--
Other Missions and Data Analysis	344.4	385.0	389.3	427.7	458.3	458.3	468.3
Discovery	**447.7**	**336.7**	**230.0**	**369.6**	**540.5**	**594.7**	**686.4**
Psyche	175.6	138.7	38.8	29.0	32.0	32.0	35.4
DAVINCI	3.5	13.5	22.8	56.7	163.3	105.5	177.5
VERITAS	6.5	13.0	57.2	123.9	154.9	223.8	250.8
Other Missions and Data Analysis	262.1	171.5	111.2	160.1	190.3	233.3	222.6
New Frontiers	**150.9**	**288.7**	**478.4**	**415.0**	**453.8**	**409.6**	**401.1**
Dragonfly	86.0	224.1	390.4	317.8	326.1	265.2	213.8
Other Missions and Data Analysis	64.9	64.6	88.1	97.2	127.6	144.4	187.3
Mars Exploration	**339.5**	**270.7**	**233.9**	**223.8**	**211.7**	**226.8**	**242.1**
Other Missions and Data Analysis	339.5	270.7	233.9	223.8	211.7	226.8	242.1
Mars Sample Return	**241.6**	**653.2**	**822.3**	**800.0**	**700.0**	**600.0**	**612.1**
Outer Planets and Ocean Worlds	**461.5**	**493.7**	**356.8**	**313.8**	**130.3**	**120.5**	**127.9**
Jupiter Europa	434.8	472.1	345.0	303.3	101.2	80.6	77.7
Other Missions and Data Analysis	26.7	21.6	11.8	10.5	29.1	39.9	50.2
Radioisotope Power	**146.3**	**148.6**	**166.3**	**189.7**	**212.1**	**199.2**	**171.0**
Astrophysics	**1,770.9**	**1,575.2**	**1,556.0**	**1,597.0**	**1,578.5**	**1,620.5**	**1,625.6**
Astrophysics Research	**249.3**	**280.3**	**329.8**	**350.8**	**345.5**	**348.4**	**350.1**
Astrophysics Research and Analysis	91.1	107.4	111.0	113.0	114.1	115.2	116.4
Balloon Project	44.8	45.8	45.7	46.3	46.3	46.3	46.3
Science Activation	45.6	55.6	55.6	55.6	55.6	55.6	55.6
Other Missions and Data Analysis	67.8	71.5	117.6	135.9	129.5	131.2	131.9
Cosmic Origins	**618.5**	**318.9**	**298.5**	**316.5**	**316.3**	**316.6**	**316.6**
Hubble Space Telescope (HST)	93.3	98.3	93.3	98.3	98.3	98.3	98.3
James Webb Space Telescope	414.7	175.4	172.5	187.0	187.0	187.0	187.0
Other Missions and Data Analysis	110.5	45.2	32.7	31.2	31.0	31.3	31.3
Physics of the Cosmos	**146.4**	**165.8**	**159.9**	**188.1**	**182.4**	**182.2**	**177.6**
Exoplanet Exploration	**552.4**	**544.7**	**522.2**	**450.2**	**423.0**	**388.4**	**258.0**
Nancy Grace Roman Space Telescope	505.2	501.6	482.2	407.3	380.0	345.7	216.6
Other Missions and Data Analysis	47.2	43.1	40.0	42.9	43.0	42.7	41.4
Astrophysics Explorer	**204.4**	**265.5**	**245.6**	**291.4**	**311.3**	**385.0**	**523.2**
Spectro-Photometer for the History of the Universe, Epoch Of Reonization, and Ices Explorer	68.5	107.9	78.7	75.0	24.0	6.0	0.1
Other Missions and Data Analysis	135.8	157.6	166.9	216.4	287.3	379.0	523.1

FY 2023 PRESIDENT'S BUDGET REQUEST SUMMARY

	Fiscal Year						
Budget Authority ($ in millions)	**Op Plan 2021**	**Request 2022**	**Request 2023**	**2024**	**2025**	**2026**	**2027**
Heliophysics	**751.0**	**797.2**	**760.2**	**802.6**	**842.0**	**851.9**	**831.9**
Heliophysics Research	**280.8**	**216.1**	**225.4**	**224.7**	**226.2**	**226.0**	**226.0**
Heliophysics Research and Analysis	77.0	52.0	53.5	52.6	54.6	56.6	56.6
Sounding Rockets	73.6	62.6	69.2	69.2	69.2	69.2	69.2
Research Range	32.0	28.2	26.9	27.9	26.9	26.9	26.9
Other Missions and Data Analysis	98.2	73.4	75.7	75.0	75.5	73.3	73.3
Living with a Star	**110.8**	**110.1**	**137.3**	**133.1**	**224.1**	**241.3**	**200.4**
Other Missions and Data Analysis	110.8	110.1	137.3	133.1	224.1	241.3	200.4
Solar Terrestrial Probes	**133.3**	**234.3**	**188.8**	**199.1**	**117.5**	**77.2**	**61.4**
Interstellar Mapping and Acceleration Probe (IMAP)	66.2	166.3	120.8	144.5	59.2	39.5	23.9
Other Missions and Data Analysis	67.1	68.0	68.0	54.6	58.3	37.7	37.5
Heliophysics Explorer Program	**162.7**	**180.2**	**157.9**	**190.9**	**222.6**	**270.2**	**307.5**
Other Missions and Data Analysis	162.7	180.2	157.9	190.9	222.6	270.2	307.5
Space Weather	**44.3**	**26.5**	**22.3**	**31.9**	**34.5**	**24.2**	**22.7**
Heliophysics Technology	**19.2**	**29.9**	**28.4**	**23.0**	**17.3**	**13.0**	**14.0**
Biological and Physical Sciences	**79.1**	**109.1**	**100.4**	**102.1**	**104.1**	**106.2**	**108.4**
Aeronautics	**828.7**	**914.8**	**971.5**	**990.9**	**1,010.7**	**1,030.9**	**1,051.5**
Aeronautics	**828.7**	**914.8**	**971.5**	**990.9**	**1,010.7**	**1,030.9**	**1,051.5**
Airspace Operations and Safety Program	**132.0**	**147.4**	**156.2**	**159.0**	**164.2**	**183.6**	**196.8**
Advanced Air Vehicles Program	**211.4**	**243.7**	**253.2**	**269.5**	**287.2**	**270.5**	**235.9**
Integrated Aviation Systems Program	**238.7**	**258.6**	**288.9**	**287.1**	**284.0**	**296.4**	**322.3**
Low Boom Flight Demonstrator	97.3	74.6	36.9	15.3	--	--	--
Electrified Powertrain Flight Demonstration	76.9	86.2	106.7	85.7	28.4	23.6	13.0
Other Projects	64.5	97.8	145.4	186.0	255.6	272.8	309.3
Transformative Aero Concepts Program	**129.7**	**148.0**	**155.9**	**158.0**	**158.0**	**163.0**	**176.6**
Aerosciences Evaluation and Test Capabilities	**116.9**	**117.0**	**117.3**	**117.3**	**117.3**	**117.3**	**119.9**
STEM Engagement	**127.0**	**147.0**	**150.1**	**153.1**	**156.2**	**159.3**	**162.5**
Safety, Security, and Mission Services	**2,936.5**	**3,049.2**	**3,208.7**	**3,272.9**	**3,338.4**	**3,405.2**	**3,473.3**
Mission Services & Capabilities	**1,918.3**	**2,028.8**	**2,154.4**	**2,197.5**	**2,241.5**	**2,286.3**	**2,332.0**
Information Technology (IT)	**548.6**	**612.2**	**667.4**	**680.8**	**694.4**	**708.3**	**722.5**
Mission Enabling Services	**702.5**	**731.5**	**761.2**	**776.4**	**792.0**	**807.8**	**823.9**
Infrastructure & Technical Capabilities	**667.2**	**685.1**	**725.8**	**740.3**	**755.1**	**770.2**	**785.6**
Engineering, Safety, & Operations	**1,018.2**	**1,020.4**	**1,054.3**	**1,075.4**	**1,096.9**	**1,118.9**	**1,141.3**
Agency Technical Authority	**182.8**	**186.8**	**195.1**	**199.0**	**203.0**	**207.0**	**211.2**

FY 2023 PRESIDENT'S BUDGET REQUEST SUMMARY

Budget Authority ($ in millions)	Op Plan 2021	Request 2022	Request 2023	2024	2025	2026	2027
Center Engineering, Safety, & Operations	835.4	833.7	859.2	876.4	893.9	911.8	930.1
Construction and Environmental Compliance and Restoration	445.8	390.3	424.3	432.8	441.5	450.3	459.3
Construction of Facilities	387.7	315.6	348.1	353.4	360.5	367.6	376.6
Institutional CoF	262.9	205.8	240.6	353.4	360.5	367.6	376.6
Exploration CoF	66.2	89.3	86.2	--	--	--	--
Space Operations CoF	25.2	20.5	21.3	--	--	--	--
Science CoF	33.4	--	--	--	--	--	--
Environmental Compliance and Restoration	58.1	74.7	76.2	79.4	81.0	82.7	82.7
Inspector General	44.2	46.0	48.4	49.4	50.4	51.4	52.4
NASA Total	23,271.3	24,801.5	25,973.8	26,493.4	27,023.3	27,563.7	28,114.8

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The FY 2023 President's budget request for NASA includes authority to transfer funds in FY 2023 from Orion Multi-purpose Crew Vehicle to Exploration Operations for Orion Production and Operations, up to $718 million, contingent on assessments following Artemis I.

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

Supporting Data

FY 2023 BUDGET REQUEST EXECUTIVE SUMMARY

Overview

Agency Summary

MESSAGE FROM THE ADMINISTRATOR

President Biden's Fiscal Year (FY) 2023 Budget for NASA reflects the Administration's confidence in this Agency, our daring missions, and the can-do spirit of our workforce. For over six decades, NASA has been a beacon of exploration, technological development, and discovery. This Budget empowers the Agency to revitalize and strengthen American leadership in aerospace, address climate change, promote equity, and expand an industry that creates good-paying American jobs.

Each investment in NASA's missions benefits the U.S. public and people around the world.

Our 2022 Strategic Plan introduces NASA's vision statement: "Exploring the secrets of the universe for the benefit of all." This underscores our commitment to achieving remarkable breakthroughs and sharing that knowledge to improve lives. NASA will expand humanity's scientific knowledge of the universe; help us better understand our planet; grow and diversify science, technology, engineering, and mathematics (STEM) education; support U.S. businesses; and promote job growth in the aerospace industry. NASA is committed to advancing diversity, equity, inclusion and accessibility to ensure fair, impartial access and representation for all those who seek to contribute to our nation's great work in space.

The Budget emphasizes NASA's leadership in climate change, as a leading provider of Earth systems science and data. This information has proven crucial for scientists, policymakers, and anyone seeking to understand and predict the effects of our changing climate. The FY 2023 Budget enables NASA to provide the world with data from its existing fleet of Earth-observing satellites and invest in a future Earth System Observatory: an array of satellites, instruments, and missions that will generate a 3D, holistic view of the entire planet. From bedrock to atmosphere, the Earth is a system. As that system changes, NASA will help us all measure and understand the nature of that change, and how we might mitigate an existential threat to our way of life.

NASA's commitment to addressing climate change goes beyond Earth science. If the United States is to remain the world leader in aviation, we must lead the world in developing sustainable aviation, overland supersonic passenger travel, and other emerging aeronautics technologies. Because green aviation is as much an issue of the future of American jobs as it is climate change, the President's Budget allows NASA to accelerate cutting-edge innovations in aerospace. The Budget supports collaborations with industry such as the Sustainable Flight National Partnership, through which NASA and U.S. companies will develop technologies that enable next generation airliners to be the most efficient ever. Meanwhile, through our Low Boom Flight Demonstrator program, we will work with communities to break down the barriers to environmentally and socially acceptable supersonic passenger flights and open up brand new markets for American companies and workers. Our commitment to this revolution in aerospace will take to the skies as two NASA experimental aircraft – the X-57 Maxwell electric demonstrator and X-59 Quiet Supersonic (QueSST) – prepare for their first flights in 2022.

Through a significant commitment for science, exploration, aeronautics, and technology, this Budget positions NASA to return humans to the Moon, including the first woman and first person of color – and continues our efforts to take humanity's next giant leap toward Mars. This year, we will launch the Space Launch System rocket and Orion spacecraft to the Moon. Together with funding for the Human Landing System, the Gateway, and lunar surface systems, this Budget enables NASA to make exciting progress towards our lunar exploration goals. With funding for lunar robotic missions, Commercial Lunar Payload Services, and other key mission elements, NASA will deepen the world's understanding of the Moon. With projects to test technologies that would allow for human exploration of Mars, including robotic explorers and the development of lunar-derived fuel and oxygen, we are advancing toward the Red Planet.

The Budget continues support for the International Space Station, which the Administration is proposing to extend through 2030, while stimulating the growth of the low-Earth orbit economy by working with industry

MESSAGE FROM THE ADMINISTRATOR

to develop commercial space stations. These investments will pave the way for continuity of sustained U. S. presence in orbit and create scientific and economic opportunities. The Agency is also increasing investments in research to ensure the growing threat of orbital debris does not interfere with our ability to safely operate in space.

The recent, remarkable launch of the James Webb Space Telescope demonstrated NASA's innovation alongside international partners – and how we benefit the world. With each great step, NASA magnifies its presence as a unifying symbol of possibility and inspiration. In addition to the scientists, engineers, technicians, and support staff who persevered to make this launch possible, NASA's endeavors use every opportunity to educate and inspire. With every breakthrough, we seek to generate more than incredible data – we help to create the next generation of scientists, engineers, and explorers who will be the innovators of the future.

The American story is about discovery, innovation, and a relentless spirit to push forward – and upward. This Budget allows NASA to continue our journey to enable a new era filled with boundless optimism and limitless possibilities for all humanity.

Bill Nelson

Bill Nelson

NOTES ON THE BUDGET

The FY 2023 President's Budget for NASA and accompanying 2022 NASA Strategic Plan are fully aligned with the Administration's priorities of restoring America's global standing; driving economic growth; addressing climate change; and promoting diversity, equity, inclusion, and accessibility. At $25.97 billion, the FY 2023 Budget for NASA underscores the Agency's unique ability to advance these priorities. With this investment, NASA will continue to lead a new era of space exploration that advances our understanding of Earth's changing climate, inspires the Nation and the world, promotes equitable opportunities to work with and for NASA, and creates good-paying jobs in the growing space economy.

NASA is a source of national inspiration and international leadership. The Agency stands ready to bring its expertise and capability to meet the challenges and opportunities facing our Nation: conducting climate research utilizing key data from our Earth observation missions to understand and mitigate climate change; supporting innovation and technology development in aviation and space; expanding key sectors of the economy while spurring growth in science, technology, engineering, and mathematics (STEM) jobs and inspiring the next generation of scientists, engineers, and explorers; and providing American leadership and global engagement through science and space exploration programs with a growing set of international partners. Through its support for exploration of the Moon, Mars, and the universe beyond, this Budget strengthens U.S leadership for a new age of human and robotic exploration and discovery.

NASA's historic and enduring purpose is captured in four Strategic Themes outlined in our 2022 Strategic Plan: Discover, Explore, Innovate, and Advance. These Strategic Themes focus the Agency's investments into four Goals: expanding human knowledge through new scientific discoveries; extending human presence to the Moon and onto Mars for sustainable long-term exploration, development, and utilization; catalyzing economic growth and driving innovation to address national challenges; and enhancing capabilities and operations to assure current and future mission success.

Discover

NASA's Science mission epitomizes the Agency's history of momentous discovery, and funds ongoing discovery and exploration of our planet, other planets and planetary bodies, our solar system, our galaxy, and the universe beyond. NASA Science includes over 100 missions, many of which involve collaboration with international partners or other U.S. agencies, and invests in world-class scientific research conducted by more than 10,000 U.S. scientists. The FY 2023 Budget delivers historic funding for Science, advancing NASA's position as a global leader in discovery.

NASA Earth Science missions are collecting ever greater amounts of data that enhance our understanding of the Earth's changing climate. NASA makes these detailed climate data freely available to the global community to inform policies and actions to address the threat climate change poses to our economic prosperity and our national security. This Budget provides $2.41 billion for NASA's Earth science portfolio and expands NASA's role as a leading provider of satellite Earth observations and other data scientists need to understand the climate crisis. With this Budget, NASA increases our ability to understand Earth and how it works as an integrated system, from our oceans to our atmosphere, and how that system is changing over time. The budget supports the decadal survey recommendation to implement "Designated" observable missions by continuing the development of the Earth System Observatory. Formulation activities are underway for missions to address the first four of these Designated observables. The Budget supports a robust Venture Class mission cadence and the launch of several upcoming missions, including NASA-ISRO Synthetic Aperture Radar (NISAR), Surface Water and Ocean Topography (SWOT), Plankton, Aerosol, Cloud, ocean Ecosystem (PACE), and Climate Absolute Radiance and Refractivity Observatory (CLARREO) Pathfinder missions, and provides funding for Earth System Explorer class missions. As part of a renewed emphasis on providing actionable data and information to a broad range of users, NASA is planning an Earth Information Center with an initial focus on prototyping capabilities for a greenhouse gas monitoring and information system that will integrate data from a variety of sources with a goal of making data more accessible and usable to Federal, State, and local governments, researchers, the public, and other users. These efforts will be implemented in coordination with other agencies and partners.

The Budget also continues to reinvigorate robotic exploration of the solar system by providing $3.16 billion for Planetary Science. The Budget funds the Lunar Discovery and Exploration program that supports collaboration with industry and innovative approaches to achieving human and science exploration goals. The Budget contains funding to explore new destinations in the solar system, including Jovian moons with Europa Clipper and the Dragonfly mission to Saturn's moon Titan, and a robust competitive Discovery program including the Psyche and Lucy missions to the asteroid belt. The Budget supports a Mars Sample Return mission with key international partnerships, which will launch as early as 2028 and return samples to Earth. The Budget also supports the Volatiles Investigating Polar Exploration Rover (VIPER) mission, which will launch on a commercial lunar delivery service and explore the south pole of the Moon. By searching for water ice and other potential resources, VIPER will help pave the way for astronaut missions to the lunar surface and will bring NASA a step closer to developing a sustainable, long-term presence on the Moon as part of the Agency's Artemis program.

The Budget builds on the transformational engineering and scientific success of the James Webb Space Telescope with $1.56 billion for Astrophysics to study the universe and search for Earth-like planets beyond our solar system. The Budget supports development of the Nancy Grace Roman Space Telescope (planned for launch in 2027) and continues operations of the Hubble Space Telescope. The Budget includes funding for a competitive Explorers program, including recent selections, such as Imaging X-ray Polarimetry Explorer (IXPE) and Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer (SPHEREx), as well as new selections every two to three years. The Budget proposes closeout of the Stratospheric Observatory for Infrared Astronomy (SOFIA) mission consistent with the recommendations of the science community; SOFIA's annual operations Budget is the second-most expensive operating mission in Astrophysics, yet the science productivity of the mission is not commensurate with other large science missions.

Heliophysics is funded at $760 million and includes support for the Interstellar Mapping and Acceleration Probe (IMAP); new missions of opportunity within the Solar Terrestrial Probes program; and new Explorer mission selections including Polarimeter to Unify the Corona and Heliosphere (PUNCH) and Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS). The Budget also includes funding for the Geospace Dynamics Constellation (GDC) mission, the Diversify, Realize, Integrate, Venture, Educate (DRIVE) initiative, and interagency efforts to improve space weather predictive capabilities (all priorities in the Heliophysics Decadal Survey).

Finally, the Budget provides $100 million for Biological and Physical Science to better understand how biological and physical systems work by observing them in ways not possible on Earth, including many experiments aboard the International Space Station (ISS). The Budget supports space biology investigations, which seek to understand how living organisms respond to and evolve in the spaceflight environment, and physical science investigations to examine the fundamental laws of the universe from the unique vantage point of space.

Explore

NASA's rich history of human spaceflight provides the foundation for today's exploration vision: to maintain U.S. leadership in space, establish a long-term presence on the Moon, and pave the way forward to Mars and beyond. NASA is leading an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring new knowledge and opportunities back to Earth. Building on the operational experience gained through more than 20 years of continuous human presence on the ISS, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations. This strategy begins with Artemis, a series of missions launched with new deep space transportation systems nearing their first flight, coupled with innovative industry capabilities including landers and space suits, that will land the first woman and the first person of color on the lunar surface. Over the next several decades, NASA will establish a long-term foothold on the lunar surface and deploy complex crewed transportation systems to the Moon and Mars. Establishing a long-term human presence on the Moon and conducting the first human mission to the surface of Mars will be among the most challenging technical enterprises in human history. This era of human exploration will require innovative technologies and systems – some of which have not yet been demonstrated – to explore new and more challenging locations, like the lunar south pole. Developing these capabilities will spur advancements in fields like space medicine, cryogenic storage, space power, materials science, and in-space manufacturing and assembly.

NASA's preparations for exploring the Moon, Mars, and beyond begin with the ISS. The FY 2023 Budget request includes $1.31 billion for ISS operations and research and $1.76 billion for crew and cargo transportation. NASA will continue to leverage its mission aboard the ISS in low-Earth orbit (LEO) to identify risks to human health, develop countermeasures, and test technologies that protect astronauts, with a continued focus on reducing operations, maintenance, and transportation costs. The ISS model of maintaining multiple domestic and international partner options for station operations and crew and cargo delivery provides functional robustness against operational risks due to technological, environmental, or other potential disruptions – a capability which has been tested before and which NASA is prepared to demonstrate again, if necessary. With $224 million of funding in this Budget, the Commercial LEO Development program supports development of commercially owned and operated LEO destinations to enable continuous American presence in LEO through 2030 and beyond. As these new space stations are being developed, NASA will be working with the ISS National Laboratory and private companies to accelerate the growth of the commercial space industries that will use the ISS and join NASA in using commercial destinations in the future.

Beyond LEO, the next step in exploration stretches out to the Moon with Artemis. The Artemis strategy includes development of common exploration systems, including the Space Launch System (SLS), Orion crew vehicle, and Exploration Ground Systems (EGS), scheduled for a full flight test on Artemis I in 2022. This Budget funds these common exploration systems at $4.67 billion, creating a transportation system for human exploration beyond LEO. With these NASA systems, the Nation will send astronauts to the Moon, building capabilities and gaining needed experience for future missions on the lunar surface and Mars. Starting in 2024, as these systems complete their developmental test flights (first with Orion, and later as SLS Block 1B development is completed), NASA will transition program management from development to exploration operations to ensure a safe, steady, and affordable cadence of flights to the Moon.

This Budget also provides $2.60 billion for Artemis Campaign Development, including the Gateway lunar outpost, the lunar Human Landing System (HLS), space suits, and lunar surface systems. Gateway will provide a platform in an orbit around the Moon to sustain surface operations, with Orion providing crew transportation services. U.S. leadership on the Gateway program has inspired Canada, Europe, and Japan to expand their partnerships with NASA to extend human presence from LEO to the Moon. The HLS program will begin with an uncrewed and then a crewed demonstration mission to the lunar surface, followed by a competition for commercial services between Gateway and the lunar surface through the latter half of the 2020s and beyond.

As part of the Artemis effort, NASA will also leverage interagency partnerships, expanding relationships with other U.S. Government agencies to take advantage of their expertise, create mutually beneficial synergies, and ensure ongoing coordination in the pursuit and achievement of the Nation's space goals. NASA will maintain and grow mutually beneficial international partnerships to lead a global community dedicated to expanding peaceful exploration and use of the Moon and then ultimately on towards Mars.

Looking to Mars, the Budget includes $161 million for Mars Campaign Development and a forward-leaning focus on reducing operational risk, validating operational concepts, leveraging partner capabilities, and lowering life cycle costs to help enable lunar and deep space missions. The Budget also includes $48 million to continue developing the detailed, integrated systems design studies needed to prepare for a human mission to Mars. Mars sample return will also advance human exploration through the demonstration of key capabilities such as round-trip planetary operations, planetary protection, and precision landing on another planetary body.

Finally, the programs in NASA's Space and Flight Support theme, with a Budget of $975 million, provide essential services to missions sponsored by all of NASA and by other stakeholders as well. Data uplinks and downlinks, unified launch service procurements that take full advantage of NASA's collective buying power to secure the best price for the Government, and other support programs provide important capabilities that support NASA's leadership in space exploration and discovery.

Innovate

NASA contributes to economic development and growth through technological innovation. Through its missions and sponsored research, NASA provides access to the farthest reaches of space and time and helps generate essential information about our home planet. NASA's cutting-edge research yields results that are used to improve quality of life and the economy here on Earth. The Nation benefits from developing new technologies that propel this exploration.

With this Budget, NASA increases funding for Aeronautics to $972 million. This Budget continues investments in research and development to enhance U.S. competitiveness in the global aviation industry, while making aviation safer, faster, more efficient, and more environmentally friendly.

To meet aggressive climate goals, the Sustainable Flight National Partnership (SFNP) with U.S. industry envisions innovative next generation single-aisle transports with game-changing, ultra-efficient, and low-carbon emitting designs at least 25 percent more fuel-efficient than today's airliners. Under the SFNP, NASA will demonstrate the first-ever high-power hybrid electric propulsion for large transport aircraft and ultra-high efficiency long and slender wings, as well as advanced composite structures produced four to six times faster than current state-of-the-art advanced engine technologies. The centerpiece of SFNP will be a full-scale technology demonstrator X-plane to test and validate integrated systems and their benefits. This partnership is a strong response to international challenges to U.S. technological leadership for next-generation subsonic transports and ensures the United States remains at the forefront of the transition to sustainability.

NASA leads transformation in other aspects of the civil aviation enterprise. The Agency is connecting the world through high-speed commercial flight, demonstrating quiet supersonic flight with NASA's X-59 Low Boom Flight Demonstrator. Through Advanced Air Mobility (AAM), Unmanned Aircraft Systems, and use of electric Vertical Takeoff and Landing vehicles, NASA is working to enable a transformation of the way people and goods move around the Nation's communities and regions. NASA is establishing partnerships with industry to mature AAM concepts and technologies for safe operations and preparing for AAM National Campaign demonstrations of new air vehicles and airspace management technologies. This year, NASA will begin flying the all-electric X-57 Maxwell aircraft to better inform standards development for small electric aircraft that will be common in an AAM environment.

The Budget supports development of the next evolution of the global air traffic management system to safely increase operational efficiency at the vehicle, fleet, and system-wide levels, while reducing fuel burn, CO_2 emissions, contrail formation, and ozone impact. NASA will expand our partnership with the Nation's universities to develop technologies to achieve the industry's long-term climate goals, while training and inspiring our future aerospace workforce. NASA will also continue to invest in critical fundamental technologies for hypersonic flight.

The $1.44 billion budget for Space Technology will develop transformative, cross-cutting technologies that lead to research and technology breakthroughs to enable NASA's missions and grow the commercial space industry through job creation. This Budget supports the Administration's priorities of enhancing research and development at NASA to maintain and enhance U.S. leadership in space technology, growing the U.S. commercial space industry and creating new, good-paying jobs, and developing new technologies to enable human and robotic exploration of the Moon, Mars, and beyond. NASA's investments advance development and demonstration of transformative capabilities for space transportation and propulsion; entry, descent, and landing, including return of robots, crew, and cargo; sustainable resource utilization and manufacturing; and robotic mobility systems. NASA will also continue demonstrating the foundational capabilities of on-orbit servicing, assembly, and manufacturing and take the next step in optical communications using infrared lasers to send data to and from space, enabling NASA to collect more science data and explore farther into the universe than ever before. In addition, NASA will continue investments in In-Situ Resource Utilization, Sustainable Power systems, lunar robotic mobility systems, research in Lunar Dust Mitigation, and small spacecraft technologies that are more rapid, affordable, and capable than previously achievable. The Budget includes $45 million for space nuclear technologies, including $30 million for surface power and $15 million for propulsion.

NASA will continue to develop technologies that have broad application and address multiple stakeholder needs, actively engaging with NASA centers, industry, academia, and other Federal Government agencies to help define program content. The Early Stage Innovation portfolio leads by sourcing ideas from a broad, diverse base of organizations and transferring space technology into the space economy. Efforts include expanding the number of NASA Innovative Advance Concepts awards and exploring innovation pilots to enable breakthrough technology research and development in support of U.S. competitiveness. These areas are part of a comprehensive approach to effectively support innovative discovery, progress toward important goals, and the development of transformative new capabilities.

Technological leadership remains vital to our national security, economic prosperity, and global competitiveness. A technology-driven, innovation-focused NASA will continue to help fuel our Nation's economic engine for decades to come, while also providing valuable breakthroughs for NASA's missions and the commercial industry.

Advance

NASA's workforce continues to be its greatest asset for advancing missions in space and on Earth. The civil service staffing levels proposed in the FY 2023 Budget fulfill NASA's requirements for scientists, engineers, researchers, managers, technicians, and business professionals. NASA's civilian workforce includes personnel at NASA centers, Headquarters, and NASA-operated facilities. The Agency's workforce will focus on high priority and enduring mission work, and NASA will endeavor to reshape, identify, recruit, and retain a multi-generational workforce that possesses the inherently governmental skills critical to the Agency.

Building on the addition of Inclusion as one of NASA's five Core Values, the funding requested in FY 2023 will help NASA focus on strengthening our diversity, equity, and inclusion policies and practices. NASA will leverage existing grant programs, small business and university partnerships, and its STEM Engagement efforts to empower underserved populations to participate in NASA research, training, and programming. NASA has long understood that diversity and inclusion is not only a matter of justice or fairness, but also a source of strength, innovation, and critical thinking.

Through the Office of STEM Engagement, NASA continues to create unique opportunities that engage students in unique, authentic learning experiences that contribute to building a diverse future STEM workforce. With a Budget of $150 million, NASA will expand initiatives to attract and retain underserved and underrepresented students in engineering and other STEM fields, in partnership with minority serving institutions and other higher education institutions. This Budget expands funding for NASA's STEM engagement efforts to equip our Nation for the future, by engaging and investing in the next generation of scientists, engineers, mathematicians, and explorers.

With a Budget of $3.21 billion, NASA's Safety, Security, and Mission Services (SSMS) account enables the Agency's portfolio of missions in space exploration, science, technology, and aeronautics. NASA manages $43 billion in assets at installations in 14 states, with an inventory of over 5,000 buildings and structures. Given a deferred maintenance backlog of $2.8 billion and the continued deterioration of NASA's facilities, approximately 30 percent of the $478 million facilities services budget is allocated to unplanned maintenance. NASA will use a portion of the remainder to continue condition-based maintenance initiatives that are reducing unplanned maintenance.

NOTES ON THE BUDGET

The SSMS account funds the essential day-to-day technical and business operations required to safely operate and maintain NASA centers and facilities and the independent technical authorities required to reduce risk to life and program objectives for all missions. These mission support activities provide the essential services, tools, and equipment to complete essential tasks, protect and maintain the security and integrity of information and assets, and ensure that personnel work under safe and healthy conditions.

Planning, operating, and sustaining our missions, infrastructure, and essential services requires institutional capabilities in management of human capital, finance, information technology, infrastructure, acquisitions, security, real and personnel property, occupational health and safety, equal employment opportunity and diversity, small business programs, external relations, strategic internal and external communications, stakeholder engagement, and other essential corporate functions. Across this array of infrastructure and essential functions, NASA continuously seeks opportunities to improve effectiveness and operate in a more efficient and sustainable manner.

NASA has a key role in better understanding the worsening orbital debris environment to support the development of innovative approaches to help protect the Nation’s satellites and reduce other risks posed by space debris. The Budget provides over $30 million for orbital debris research, early-stage technology, and measurement technologies.

Finally, the Construction and Environmental Compliance and Restoration (CECR) account enables NASA to manage the Agency’s facilities with a focus on maintaining safe, sustainable assets that meet critical mission needs. With an FY 2023 Budget of $424 million for CECR, NASA will continue to reduce its footprint by consolidation of facilities via institutional construction projects. NASA will also achieve greater operational efficiency by replacing old, obsolete, and costly facilities with fewer, higher performance facilities. Programmatic construction projects in the FY 2023 Budget will provide specialized technical facilities required by the missions. To protect human health and the environment, and to preserve natural resources for future missions, environmental compliance and restoration projects will remediate pollutants released into the environment during prior NASA activities.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

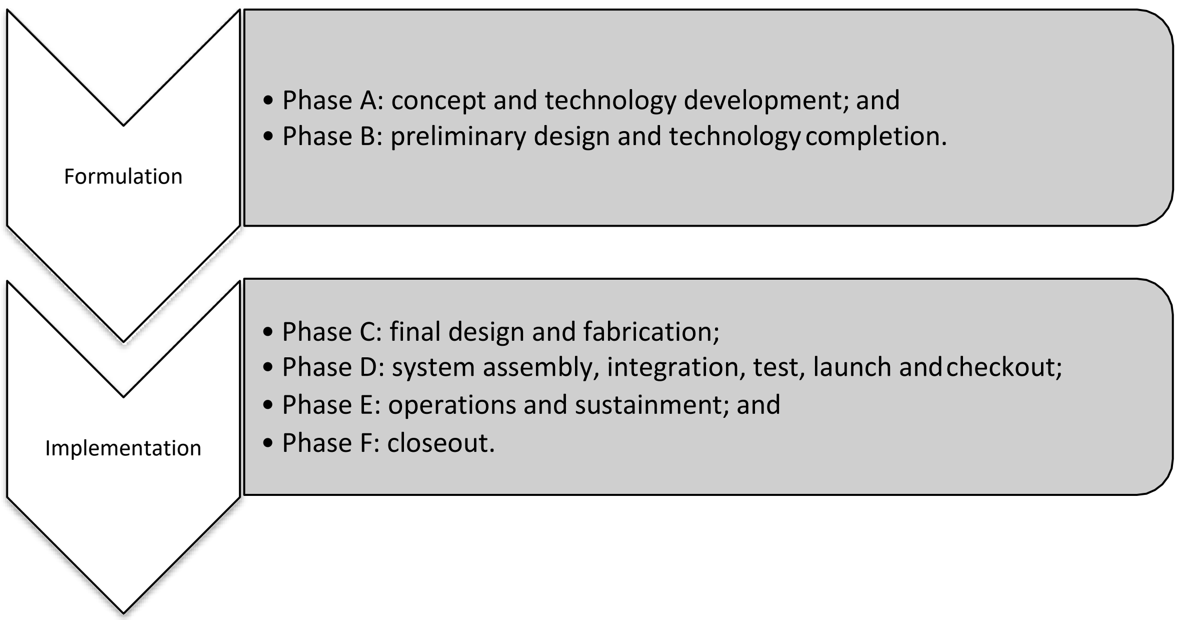
FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

EXPLANATION OF PROJECT SCHEDULE COMMITMENTS AND KEY MILESTONES

Programs and projects follow their appropriate life cycle. The life cycle is divided into phases. Transition from one phase to another requires management approval at Key Decision Points (KDPs). The phases in program and project life cycles include one or more life-cycle reviews, which are considered major milestone events.



A life-cycle review is designed to provide the program or project with an opportunity to ensure that it has completed the work of that phase and an independent assessment of a program's or project's technical and programmatic status and health. The final life-cycle review in a given life-cycle phase provides essential information for the KDP that marks the end of that life-cycle phase and transition to the next phase if successfully passed. As such, KDPs serve as gates through which programs and projects must pass to continue.

The KDP decision to authorize a program or project's transition to the next life-cycle phase is based on a number of factors, including technical maturity; continued relevance to Agency strategic goals; adequacy of cost and schedule estimates; associated probabilities of meeting those estimates (confidence levels); continued affordability with respect to the Agency's resources; maturity and the readiness to proceed to the next phase; and remaining program or project risk (safety, cost, schedule, technical, management, and programmatic). At the KDP, the key program or project cost, schedule, and content parameters that govern the remaining life-cycle activities are established.

For reference, a description of schedule commitments and milestones is listed below for projects in Formulation and Implementation. A list of common terms used in mission planning is also included.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

Formulation

NASA places significant emphasis on project Formulation to ensure adequate preparation of project concepts and plans and mitigation of high-risk aspects of the project essential to position the project for the highest probability of mission success. During Formulation, the project explores the full range of implementation options, defines an affordable project concept to meet requirements, and develops needed technologies. The activities in these phases include developing the system architecture; completing mission and preliminary system designs; acquisition planning; conducting safety, technical, cost, and schedule risk trades; developing time-phased cost and schedule estimates and documenting the basis of these estimates; and preparing the Project Plan for Implementation.

Formulation Milestone	Explanation
KDP-A	The lifecycle gate at which the decision authority determines the readiness of a program or project to transition into Phase A and authorizes Formulation of the project. Phase A is the first phase of Formulation and means that: • The project addresses a critical NASA need; • The proposed mission concept(s) is feasible; • The associated planning is sufficiently mature to begin activities defined for formulation; and • The mission can likely be achieved as conceived.
System Requirements Review (SRR)	The lifecycle review in which the decision authority evaluates whether the functional and performance requirements defined for the system are responsive to the program's requirements on the project and represent achievable capabilities
System Definition Review or Mission Definition Review	The lifecycle review in which the decision authority evaluates the credibility and responsiveness of the proposed mission/system architecture to the program requirements and constraints on the project, including available resources, and determines whether the maturity of the project's mission/system definition and associated plans are sufficient to begin the next phase, Phase B.
KDP-B	The lifecycle gate at which the decision authority determines the readiness of a program or project to transition from Phase A to Phase B. Phase B is the second phase of Formulation and means that: • The proposed mission/system architecture is credible and responsive to program requirements and constraints, including resources; • The maturity of the project's mission/system definition and associated plans is sufficient to begin Phase B; and • The mission can likely be achieved within available resources with acceptable risk.
Preliminary Design Review (PDR)	The lifecycle review in which the decision authority evaluates the completeness/consistency of the planning, technical, cost, and schedule baselines developed during Formulation. This review also assesses compliance of the preliminary design with applicable requirements and determines if the project is sufficiently mature to begin Phase C.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

Implementation

Implementation occurs when Agency management establishes baseline cost and schedule commitments for projects at KDP-C. The projects maintain the baseline commitment through the end of the mission. Projects are baselined for cost, schedule, and programmatic and technical parameters. Under Implementation, projects are able to execute approved plans development and operations.

Implementation Milestone	Explanation
KDP-C	The lifecycle gate at which the decision authority determines the readiness of a program or project to begin the first stage of development and transition to Phase C and authorizes the Implementation of the project. Phase C is first stage of development and means that: • The project's planning, technical, cost, and schedule baselines developed during Formulation are complete and consistent; • The preliminary design complies with mission requirements; • The project is sufficiently mature to begin Phase C; and • The cost and schedule are adequate to enable mission success with acceptable risk.
Critical Design Review (CDR)	The lifecycle review in which the decision authority evaluates the integrity of the project design and its ability to meet mission requirements with appropriate margins and acceptable risk within defined project constraints, including available resources. This review also determines if the design is appropriately mature to continue with the final design and fabrication phase.
System Integration Review (SIR)	The lifecycle review in which the decision authority evaluates the readiness of the project and associated supporting infrastructure to begin system assembly, integration, and test. The lifecycle review also evaluates whether the remaining project development can be completed within available resources, and determine if the project is sufficiently mature to begin Phase D.
KDP-D	The lifecycle gate at which the decision authority determines the readiness of a project to continue in Implementation and transition from Phase C to Phase D. Phase D is a second phase in Implementation; the project continues in development and means that: • The project is still on plan; • The risk is commensurate with the project's payload classification; and • The project is ready for assembly, integration, and test with acceptable risk within its Agency baseline commitment.
Launch Readiness Date (LRD)	The date at which the project and its ground, hardware, and software systems are ready for launch.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

Other Common Terms for Mission Planning

Term	Definition
Decision Authority	The individual authorized by the Agency to make important decisions on programs and projects under their authority.
Formulation Authorization Document	The document that authorizes the formulation of a program whose goals will fulfill part of the Agency's Strategic Plan and Mission Directorate strategies. This document establishes the expectations and constraints for activity in the Formulation phase.
Key Decision Point (KDP)	The lifecycle gate at which the decision authority determines the readiness of a program or project to progress to the next phase of the life cycle. The KDP also establishes the content, cost, and schedule commitments for the ensuing phase(s).
Launch Manifest	A list that NASA publishes (the "NASA Flight Planning Board launch manifest") periodically, which includes the expected launch dates for NASA missions. The launch dates in the manifest are the desired launch dates approved by the NASA Flight Planning Board and are not typically the same as the Agency Baseline Commitment schedule dates. A launch manifest is a dynamic schedule that is affected by real world operational activities conducted by NASA and multiple other entities. It reflects the results of a complex process that requires the coordination and cooperation by multiple users for the use of launch range and launch contractor assets. Moreover, the launch dates are a mixture of "confirmed" range dates for missions launching within approximately six months, and contractual/planning dates for the missions beyond six months from launch. The NASA Flight Planning Board launch manifest date is typically earlier than the Agency Baseline Commitment schedule date to allow for the operationally driven delays to the launch schedule that may be outside of the project's control.
Operational Readiness Review	The lifecycle review in which the decision authority evaluates the readiness of the project, including its ground systems, personnel, procedures, and user documentation, to operate the flight system and associated ground system(s), in compliance with defined project requirements and constraints during the operations phase.
Mission Readiness Review or Flight Readiness Review (FRR)	The lifecycle review in which the decision authority evaluates the readiness of the project, ground systems, personnel and procedures for a safe and successful launch and flight/mission.
KDP-E	The lifecycle gate at which the decision authority determines the readiness of a project to continue in Implementation and transition from Phase D to Phase E. Phase E is a third phase in Implementation and means that the project and all supporting systems are ready for safe, successful launch and early operations with acceptable risk.
Decommissioning Review	The lifecycle review in which the decision authority evaluates the readiness of the project to conduct closeout activities. The review includes final delivery of all remaining project deliverables and safe decommissioning of space flight systems and other project assets.
KDP-F	The lifecycle gate at which the decision authority determines the readiness of the project's decommissioning. Passage through this gate means the project has met its program objectives and is ready for safe decommissioning of its assets and closeout of activities. Scientific data analysis may continue after this period.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

For further details, go to:

- NASA Procedural Requirement 7120.5F NASA Space Flight Program and Project Management Requirements: https://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7120&s=5F
- NASA Procedural Requirement NPR 7123.1B - NASA Systems Engineering Processes and Requirements: http://nodis3.gsfc.nasa.gov/npg_img/N_PR_7123_001B_/N_PR_7123_001B_.pdf.
- NASA Launch Services Web site: http://www.nasa.gov/directorates/heo/launch_services/index.html.

NASA AND COVID-19

Since March 2020, NASA (along with the rest of the world) has adapted to the historic challenges of COVID-19. As COVID-19 cases surged across the country, NASA quickly adopted a new operational model that included a dramatic increase in off-site telework, transitioning from in-person scientific and technical interchange meetings to virtual and hybrid events, and instituting protocols to allow personnel building flight hardware to safely work at NASA and contractor facilities. Under this new operating model, NASA has conducted some of the most ambitious missions in its history, including the landing the Perseverance rover on Mars and the first flight of a helicopter on another planet, the first launch of commercial crew transportation to the International Space Station, and the launch and deployment of the revolutionary James Webb Space Telescope. Throughout the COVID-19 pandemic, NASA has prioritized the health and productivity of its workforce, a focus reflected in the Agency's continued ranking by employees as the best place to work in the Federal Government.

COVID-19 has impacted NASA projects in multiple ways, including: facility shutdowns, restarts, and reduced on-site access due to social distancing and cleaning protocols; interruptions to test and construction efforts; disruptions in travel to both domestic and international partner locations; and pressures on the overall aerospace supply chain. NASA cost reserves and schedule margins are under pressure as projects utilize some of those resources to offset COVID-19-related impacts. These pandemic-related pressures on cost reserves and schedule margin, in turn, leave fewer reserves and margins to address other risks that are expected in development of NASA's complex missions.

To date, NASA has notified Congress of nine projects across the Agency that have experienced cost and schedule growth due in part to COVID-19 pressures. These projects include the Roman Space Telescope, James Webb Space Telescope, Geostationary Carbon Observatory (GeoCarb), Surface Water and Ocean Topography (SWOT), the NASA-Indian Space Research Organization Synthetic Aperture Radar (NISAR), the Orion exploration crew vehicle, the On-orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1) and Solar Electric Propulsion (SEP) technology demonstration missions, and the Low-Boom Flight Demonstration (LBFD).

It is difficult to project a specific estimate of the total long term impact of COVID-19 on Agency programs and missions at this time. In March 2021, the NASA Office of the Inspector General noted that the total Agency impact due to COVID-19 could be nearly $3 billion[1]. Even as COVID-19 appears to be transitioning from a pandemic emergency to a more long term endemic health issue, a final accounting of the full impact of the COVID-19 pandemic on Agency activities will not be available until well after the Agency and its contractors have resumed normal operations.

[1] *COVID-19 Impacts on NASA's Major Programs and Projects, IG-20-016, March 31, 2021*

DEEP SPACE EXPLORATION SYSTEMS

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Common Exploration Systems Development	4,538.7	4,483.7	**4,668.4**	3,613.8	3,111.9	2,845.6	2,376.8
Artemis Campaign Development	1,672.1	2,062.0	**2,600.3**	2,973.8	3,489.3	3,853.9	4,450.7
Human Exp Requirements & Architecture	9.5	9.5	**48.3**	48.9	49.5	50.0	50.5
Mars Campaign Development	176.2	195.0	**161.3**	161.6	162.7	162.7	162.8
Total Budget	**6,396.5**	**6,750.2**	**7,478.3**	**6,798.1**	**6,813.4**	**6,912.3**	**7,040.8**

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The FY 2023 President's budget request for NASA includes authority to transfer funds in FY 2023 from Orion Multi-purpose Crew Vehicle to Exploration Operations for Orion Production and Operations, up to $718 million, contingent on assessments following Artemis I.

DEEP SPACE EXPLORATION SYSTEMS

DEEP SPACE EXPLORATION SYSTEMS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Common Exploration Systems Development	4,538.7	4,483.7	**4,668.4**	3,613.8	3,111.9	2,845.6	2,376.8
Artemis Campaign Development	1,672.1	2,062.0	**2,600.3**	2,973.8	3,489.3	3,853.9	4,450.7
Human Exp Requirements & Architecture	9.5	9.5	**48.3**	48.9	49.5	50.0	50.5
Mars Campaign Development	176.2	195.0	**161.3**	161.6	162.7	162.7	162.8
Total Budget	**6,396.5**	**6,750.2**	**7,478.3**	**6,798.1**	**6,813.4**	**6,912.3**	**7,040.8**
Change from FY 2022 Budget Request			**728.1**				
Percent change from FY 2022 Budget Request			**10.8%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The FY 2023 President's budget request for NASA includes authority to transfer funds in FY 2023 from Orion Multi-purpose Crew Vehicle to Exploration Operations for Orion Production and Operations, up to $718 million, contingent on assessments following Artemis I.

The FY 2023 budget request includes $7.478 billion for Deep Space Exploration Systems to pursue the Artemis Campaign, which is focused on returning humans to the Moon, conducting pioneering research and technology development activities on the lunar surface, and enabling eventual missions to Mars and beyond. In a series of Artemis missions, NASA will land the first woman and first person of color on the Moon and will explore more of the lunar surface than ever before. In collaboration with our commercial and international partners, NASA will create the capabilities necessary to sustainably explore the Moon. The operational knowledge, technological advances, and scientific discoveries we gain from exploring the Moon in collaboration with international and commercial partners will position us to take the next giant leap - sending astronauts to Mars.

The Exploration Systems Mission Directorate (ESDMD) will leverage the Science Mission Directorate's (SMD) development of smaller landers for capabilities such as navigation and precision landing as well as for the data about the lunar surface that they will provide. It will also leverage investments through the Space Technology Mission Directorate's (STMD) lunar exploration activities. The Deep Space Exploration Systems account consists of four themes which provide for the development of systems and capabilities needed for human exploration of space:

- Common Exploration Systems Development (CESD);
- Artemis Campaign Development (ACD);
- Human Exploration Requirements & Architecture (HERA);
- Mars Campaign Development (MCD).

DEEP SPACE EXPLORATION SYSTEMS

This is a new organizational structure for the FY 2023 Budget that reflects the reorganization of the former Human Exploration and Operations Mission Directorate, with CESD (previously Exploration Systems Development) being renamed, and ACD, HERA, and MCD replacing the retired Exploration Research and Development (ERD) theme.

NASA's CESD programs are working together to build the space transportation system made up of the Orion crew vehicle, Space Launch System (SLS) rocket, and Exploration Ground Systems (EGS). This system will enable the Agency's Artemis missions, extending human presence into the solar system by transporting crews to lunar orbit and safely back to Earth in preparation for future missions to Mars.

The ACD theme is comprised of three programs previously funded under the Exploration Research and Development (ERD) theme: Advanced Cislunar and Surface Capabilities (ACSC), Gateway, Human Landing System (HLS), and one newly formed program: Exploration Extravehicular Activity (xEVA) and Human Surface Mobility. The overarching goal of ACD is to develop the systems that will be used to land humans on the Moon, explore the lunar surface, and prepare for Mars exploration. ACD is both developing and testing prototype systems, as well as planning and developing flight missions to lunar orbit and the Moon to develop systems and operation capabilities that enable an eventual mission to Mars. ACD's work will create the exploration infrastructure in lunar orbit and on the lunar surface that astronauts will use during Artemis missions and that will inform future missions to Mars.

The overarching goal of HERA is to provide support in the development of human exploration campaigns to the Moon and beyond. HERA's work will identify the exploration infrastructure required for Artemis missions that will inform future missions to Mars. It also works to ensure that lunar exploration systems are extensible to Mars exploration where technically feasible and cost-effective. HERA includes the Moon & Mars Architecture Development Office which manages the architecture strategy activity that supports mission manifest planning and overall architecture requirements and capability identification. HERA also maintains the Systems Engineering and Integration (SE&I) required to support the top-level technical integration across ESDMD, Space Operations Mission Directorate (SOMD), SMD, and STMD to include Artemis missions and future exploration planning.

The overarching goal of the new MCD theme is to start working on long-lead technology challenges that will need to be solved in order for an eventual crewed mission to Mars to succeed. Together with ACD, MCD is both developing and testing prototype technologies, as well as contributing to the planning and development of flight missions to lunar orbit and the Moon to develop systems and operations capabilities that enable an eventual mission to Mars. The Exploration Capabilities Program develops habitation systems technologies to enable long missions on the lunar surface and in deep space as well as fill high priority technology gaps. MCD will begin conducting preliminary concept studies for future systems, including an eventual transit habitat that will provide living quarters and other basic life support functions for an eventual human mission to Mars.

EXPLANATION OF MAJOR CHANGES IN FY 2023

- Renames the old Exploration Systems Development theme as Common Exploration Systems Development.
- Moved Orion Production and Sustainment as well as Exploration Operations Program funding to Space Operations account.
- Establishes Artemis Campaign Development as a new theme that contains the Gateway, HLS and ACSC programs that previously resided under the ERD theme. Establishes the xEVA and Human Surface Mobility program as the fourth program within ACD.

DEEP SPACE EXPLORATION SYSTEMS

- Establishes Human Exploration Requirements & Architecture as a new theme.
- Establishes Mars Campaign Development as a new theme that contains the Exploration Capabilities program that previously resided under the ERD theme.

For more information, go to: https://www.nasa.gov/directorates/exploration-systems-development

COMMON EXPLORATION SYSTEMS DEVELOPMENT

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Enacted FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Orion Program	1,403.7	1,406.7	**1,338.7**	415.0	116.5	52.0	19.0
Crew Vehicle Development	1,387.8	1,388.8	**1,325.3**	415.0	116.5	52.0	19.0
Orion Program Integration and Support	15.9	17.9	**13.4**	0.0	0.0	0.0	0.0
Space Launch System	2,555.0	2,487.0	**2,579.8**	2,534.6	2,484.6	2,326.5	1,925.5
Launch Vehicle Development	2,488.4	2,414.0	**2,505.7**	2,455.8	2,393.2	2,234.4	1,832.7
SLS Program Integration and Support	66.6	73.0	**74.0**	78.8	91.3	92.0	92.7
Exploration Ground Systems	580.0	590.0	**749.9**	664.2	510.8	467.2	432.3
Exploration Ground Systems Development	569.2	585.3	**747.3**	660.0	503.8	460.0	425.0
EGS Program Integration and Support	10.8	4.7	**2.6**	4.2	7.0	7.2	7.3
Construction & Envrmtl Compl Restoration	66.2	89.3	**86.2**	0.0	0.0	0.0	0.0
Exploration CoF	66.2	89.3	**86.2**	0.0	0.0	0.0	0.0
Total Budget	**4,604.9**	**4,573.0**	**4,754.6**	**3,613.8**	**3,111.9**	**2,845.6**	**2,376.8**
Change from FY 2022 Budget Request			**181.6**				
Percent change from FY 2022 Budget Request			**4.0%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The FY 2023 President's budget request for NASA includes authority to transfer funds in FY 2023 from Orion Multi-purpose Crew Vehicle to Exploration Operations for Orion Production and Operations, up to $718 million, contingent on assessments following Artemis I.

COMMON EXPLORATION SYSTEMS DEVELOPMENT

The core stage for the first flight of NASA's Space Launch System rocket is seen in the B-2 Test Stand during a second hot fire test, on Thursday, March 18, 2021. This took place at NASA's Stennis Space Center near Bay St. Louis, Mississippi. The four RS-25 engines fired for the full-duration of eight minutes during the test and generated 1.6 million pounds of thrust. The hot fire test is the final stage of the Green Run test series, a comprehensive assessment of the Space Launch System's core stage prior to launching the Artemis I. mission.

NASA's Common Exploration Systems Development (CESD) programs are working together to build the space transportation system made up of the Orion crew vehicle, the Space Launch System (SLS) rocket, and the Exploration Ground Systems (EGS). This system will enable the Agency's Artemis missions, extending human presence into the solar system by transporting crews to the Gateway or to the Moon's surface in the Human Landing System for long-term exploration and in preparation for future missions to Mars. The CESD program objectives support Agency Strategic Goal 2, which seeks to extend human presence to the Moon and on towards Mars for sustainable long-term exploration, development, and utilization.

NASA's Orion spacecraft is designed to support human exploration missions to deep space, with a crew of four, with habitation and life support on-board for missions up to 21 days. Building upon more than 50 years of spaceflight research and development, Orion's versatile design will not only carry crew to space, but also provide emergency abort capability, sustain crew during space travel, and provide safe reentry at deep space return velocities. The Orion systems are designed to operate in a contingency mode to augment life support systems in other space transport systems.

The SLS rocket is a heavy-lift launch vehicle that will launch astronauts in the Orion spacecraft on missions to cislunar space so they can return to the surface of the Moon and visit other destinations. The Block 1 configuration, which is the configuration for Artemis I, stands at 322 feet and features a lift capability of 95 metric tons to low-Earth orbit (LEO), and over 27 metric tons to translunar injection for Moon missions with 8.8 million pounds of maximum thrust. The evolution of the architecture, currently planned for first use on Artemis IV, will include an Exploration Upper Stage (EUS), associated Universal Stage Adapter, and Payload Adapter which provides space for co-manifested payloads. This Block 1B configuration will be capable of delivering at least 37.3 metric tons of net payloads to Trans-Lunar Injection on crewed missions. The 37.3 metric ton total includes Orion, which weighs 27 metric tons.

The objective of EGS is to enable Kennedy Space Center (KSC) to process and launch Orion and SLS in support of the Artemis missions. To achieve this transformation, NASA is developing new ground systems while refurbishing and upgrading infrastructure and facilities to meet tomorrow's demands.

The Artemis Campaign is the next step in human exploration of our solar system. It is a part of NASA's Moon to Mars exploration approach, in which NASA will pursue its next giant leap, sustained human exploration of the Moon, to develop the skills, systems, and operational capabilities required to enable human missions to Mars. As NASA works towards a sustainable Moon to Mars campaign, it is essential the Agency and its contractors reduce production and operations costs for CESD systems, and NASA is examining options to achieve this goal. Through a reduction in CESD program costs, the Agency can focus on the many other capabilities needed for future deep space systems and successful exploration missions.

ORION PROGRAM

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Crew Vehicle Development	1,387.8	1,388.8	**1,325.3**	415.0	116.5	52.0	19.0
Orion Program Integration and Support	15.9	17.9	**13.4**	0.0	0.0	0.0	0.0
Total Budget	**1,403.7**	**1,406.7**	**1,338.7**	**415.0**	**116.5**	**52.0**	**19.0**
Change from FY 2022 Budget Request			**-68.0**				
Percent change from FY 2022 Budget Request			**-4.8%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The FY 2023 President's budget request for NASA includes authority to transfer funds in FY 2023 from Orion Multi-purpose Crew Vehicle to Exploration Operations for Orion Production and Operations, up to $718 million, contingent on assessments following Artemis I.

The picture above is Artemis III Crew Module (CM) in the Operation and Checkout building (O&C) at Kennedy Space Center (KSC) for processing.

The Orion spacecraft will play an integral role in the Artemis Campaign, serving as an exploration vehicle that will carry crew to space, sustain the crew during space travel, provide emergency abort capability, and provide safe re-entry from deep space return velocities for Artemis Missions. This capsule-shaped vehicle has a familiar look, but it incorporates numerous technology advancements and innovations. The spacecraft will enable extended duration missions beyond low-Earth orbit, to the Moon, and eventually to Mars.

Development of the Orion spacecraft will be completed after the Artemis II mission and development of the Rendezvous, Proximity Operations and Docking (RPOD) capability for the Artemis III mission. Orion's design, development, testing (including the flight tests), and evaluation will have the spacecraft ready to carry crew on Artemis II with a current launch date of no earlier than May 2024 and ready to support subsequent Artemis missions. The budget request supports launches at the earliest technically feasible dates.

To align with the Agency reorganization implemented in FY 2022, production and sustainment of crew vehicles for Artemis III and beyond will be budgeted in the Exploration Operations theme in the Space Operations account. Residual development activity will continue to be funded in the DSES account.

The full Orion Program will continue to be managed by a single Orion Program Office, with a single Orion Program Manager, which will manage the Orion funds in both the DSES and Space Operations accounts. Orion's interfaces with other NASA programs and with the prime contractor and other contractors will remain unchanged.

ORION PROGRAM

The full budget for the Orion Program is as follows:

(in $ millions)	FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Integration and Support	15.9	17.9	13.4	-	-	-	-
Development	1,387.8	1,388.8	1,325.3	415.0	116.5	52	19
Orion Exploration Total	**1,403.7**	**1,406.7**	**1,338.7**	**415.0**	**116.5**	**52.0**	**19.0**
Production and Sustainment	-	-	TBD	786.9	925.3	990.2	1,022.5
Operations	-	-	TBD	46.0	47.0	47.0	48.0
Orion Space Ops Total	**-**	**-**	**-**	**832.9**	**972.3**	**1,037.2**	**1,070.5**
Orion Program Total	**1,403.7**	**1,406.7**	**1,338.7**	**1,247.9**	**1,088.8**	**1,089.2**	**1,089.5**

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The FY 2023 President's budget request for NASA includes authority to transfer funds in FY 2023 from Orion Multi-purpose Crew Vehicle to Exploration Operations for Orion Production and Operations, up to $718 million, contingent on assessments following Artemis I.

For more information, go to: http://www.nasa.gov/orion

Program Elements

ORION PROGRAM INTEGRATION AND SUPPORT

Orion Program Integration and Support activities manage the program interfaces between the Space Launch System and the Exploration Ground Systems. This effort is critical to ensuring Orion's performance meets technical and safety specifications, and it supports programmatic assessments key to achieving integrated technical, cost, and schedule management. In addition, the Orion integration effort is vital to managing interfaces with other Exploration Systems Development Mission Directorate (ESDMD) and Space Operations Mission Directorate (SOMD) activities, including strategic studies, feasibility studies, and small-scale research tasks that feed into future human exploration. Coordination and timely integration across ESDMD are aimed at mitigating the impacts of potential design overlaps, schedule disconnects and delays, and cost overruns.

ORION PROGRAM

CREW VEHICLE DEVELOPMENT

Orion will be capable of transporting humans to orbit around the Moon, sustaining them for longer durations beyond low-Earth orbit than ever before, providing emergency abort capability, and returning them safely to Earth. See the Crew Vehicle Development section starting on the next page for additional details.

ORION PRODUCTION AND SUSTAINMENT (FUNDED IN SPACE OPERATIONS)

Described in the Space Operations account, Exploration Operations theme.

EXPLORATION OPERATIONS PROGRAM (FUNDED IN SPACE OPERATIONS)

Described in the Space Operations account, Exploration Operations theme.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

FY 2023 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027	BTC	Total
Formulation	4,509.6	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	4,509.6
Development/Implementation	6,870.9	788.4	816.1	**513.0**	197.8	115.1	0.0	0.0	0.0	9,301.2
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2022 MPAR LCC Estimate	**11,380.5**	**788.4**	**816.1**	**513.0**	**197.8**	**115.1**	**0.0**	**0.0**	**0.0**	**13,810.8**
Total Budget	**11,605.2**	**1,387.8**	**1,388.8**	**1,325.3**	**415.0**	**116.5**	**52.0**	**19.0**	**0.0**	**16,309.6**
Change from FY 2022 Budget Request				**-63.5**						
Percent change from FY 2022 Budget Request				**-4.6%**						

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The difference between the total budget and the MPAR LCC estimate is the total budget includes content outside of Artemis II and excludes CoF; LCC only includes Artemis II content, including CoF.

The total budget prior line represents FY 2011 pre-formulation and FY 2012 - FY 2020 budgets, excluding CoF and additional expenditures from 2005-2011 under the Constellation program.

The FY 2023 President's budget request for NASA includes authority to transfer funds in FY 2023 from Orion Multi-purpose Crew Vehicle to Exploration Operations for Orion Production and Operations, up to $718 million, contingent on assessments following Artemis I.

Artemis II European Service Module (ESM) and Artemis III Crew Module (CM) pressure vessel side by side in the Operations and Checkout (O&C) building at Kennedy Space Center (KSC).

PROJECT PURPOSE

Orion will be capable of transporting humans to orbit around the Moon, sustaining them for longer durations beyond low-Earth Orbit than ever before, providing emergency abort capability, and returning them safely to Earth. Drawing from more than 50 years of human spaceflight research and development, as well as stimulating new and innovative manufacturing and production capabilities, Orion's design will meet the evolving needs of our Nation's space program.

For more information, go to http://www.nasa.gov/orion

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2023

The proposed funding levels provide the necessary resources for the Artemis I launch. They are also sufficient allow the program to support Artemis II and III launches as soon as is technically feasible. After analyzing programmatic milestones, NASA has moved the target launch date for Artemis I to no earlier than (NET) May 2022 and Artemis II target launch date to NET May 2024. During calendar year 2021, the Orion Program re-baselined their Agency Baseline Commitment (ABC) and related budget to reflect the Artemis II changes.

PROJECT PARAMETERS

Orion is the vehicle that will fly astronauts from Earth to orbits around the Moon and back again. Orion will be able to carry a crew of four astronauts to cislunar space and beyond, as well as provide habitation and life support for up to 21 days. The spacecraft's four elements are the Crew Module (CM), the Crew Module Adaptor (CMA), the European Service Module (ESM), and the Launch Abort System (LAS). The European Space Agency (ESA) is designing and developing the ESM, which provides in-space power, propulsion, and other life support systems. The CM, which is the pressure vessel, will mount to the CMA and ESM to become the Crew and Service Module (CSM). Atop the CSM will sit the LAS, which will activate within milliseconds to propel the CM to safety away from the launch vehicle in the event of an emergency during launch or ascent to orbit. The abort system also provides a protective shell that shields the CM from dangerous atmospheric loads and heating during ascent. Once Orion is out of the atmosphere and safely on its way to orbit, the spacecraft will jettison the LAS.

Orion's first mission is Artemis I, an uncrewed flight test that will demonstrate key Orion spacecraft capabilities. The next mission, Artemis II, is a crewed test flight, with a current mission profile of transporting up to four crewmembers on a free return trajectory around the Moon. For Artemis III, the first Artemis mission to the lunar surface, the Orion spacecraft will rendezvous and dock with Gateway or the Human Landing System (HLS) spacecraft. The crew and necessary equipment will transfer from the Orion spacecraft, potentially via Gateway, into the HLS, which will then undock, descend, and land on the lunar surface. At the conclusion of the lunar surface operations, the HLS will lift off from the lunar surface. The HLS will re-dock with Gateway or the Orion spacecraft where the crew will transfer back into Orion for their return to Earth. Although the module has a familiar visual shape, its interior and exterior capabilities far exceed any geometrically similar predecessors. The crew systems will provide a safe environment for astronauts to live and work for 21 days during missions far from Earth. Orion's advanced heat shield will protect the crew during a high-speed reentry into Earth's atmosphere, heating that will exceed that experienced by any human spacecraft in more than five decades. For Artemis IV and subsequent lunar missions, Orion will dock with the Gateway in a Near-Rectilinear Halo Orbit around the Moon, giving astronauts access to more areas of the lunar surface and better communication capabilities than the Apollo program.

ACHIEVEMENTS IN FY 2021

European Service Module (ESM)-1 Acceptance Review was completed, a milestone which transferred ownership from ESA to NASA.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Lockheed Martin completed the final installations on the Artemis I CSM and handed the vehicle over to Exploration Ground Systems (EGS) for ground operations. Following the handover, the CSM was moved to the Multi-Purpose Processing Facility (MPPF) for servicing with hypergolic propellants, high pressure gas, and ammonia. In addition, the installation of the LAS and ogive panels and functional tests were also completed.

Artemis I flight software load 28E and Patch 9 was released. The flight software covers all phases of Orion flight from pre-launch through post-landing.

The CM Structural Test Article (STA) arrived at Langley Research Center (LaRC) in Hampton, VA, for a series of Water Impact Tests (WIT) to assess the impact to the spacecraft's primary and secondary structures under water landing conditions. The WIT campaign included three vertical drops and one swing test. Data from this test campaign will be used as final model correlation for Artemis II loads and structural verification, and the Artemis II flight.

Installation of the Artemis II CM Environmental Control and Life Support System (ECLSS) and propulsion subassemblies as well as proof pressure and leak tests were completed at KSC's Operations and Checkout (O&C) building. Orion's propulsion system will provide the propulsive capability to transport the spacecraft for the duration of the mission after separation from SLS's Interim Cryogenic Propulsion State (IPCS). ECLSS will provide the crew with a pressure and temperature-controlled environment, breathable air, and potable water during the mission.

Orion completed Artemis II CMA ECLSS and propulsion proof and leak testing. Avionics, power subsystems and wire harnesses were installed in the Artemis II CMA.

Preparations for the Artemis II heatshield thermal cycle testing were completed. The ablative Avcoat resin material will protect the crewed spacecraft as it experiences temperatures up to 5000 Fahrenheit during high-speed entry into the Earth’s atmosphere.

Lastly, Artemis II software build 203 was released. The software build provides for entry mission and supports the CSM-2 initial power-on procedure checkout in the Integrated Test Lab (ITL).

WORK IN PROGRESS IN FY 2022

Orion delivered an early release of software build 204 for the on-orbit mission phase in October 2021 and formal release of software build 204 will take placed in March 2022. The integrated test of software build 204 for the on-orbit portion of the Artemis II mission, ITL-204, began in August 2021 and will conclude in May 2022.

The Artemis I spacecraft processing activities concluded with Thermal Protection System (TPS) closeout tasks and final vehicle inspections. Following those activities, the Orion spacecraft was successfully mated to the Space Launch System (SLS) in October 2021 in the Vehicle Assembly Building (VAB) at KSC.

A series of Artemis I integrated tests are currently underway and will culminate in a Wet Dress Rehearsal (WDR) of the integrated stack on the Mobile Launcher at Launch Pad 39B no earlier than April 2022. The launch of the Artemis I mission, planned for NET May 2022 will take the Orion spacecraft beyond the Moon and demonstrate its performance capability during launch, transit to lunar orbit, return to Earth, re-entry, landing, and recovery.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

After the Artemis I mission, the Orion Program will conduct a post-flight analysis to assess spacecraft performance against flight test objectives. The program will recover certain non-core avionics components from the returned spacecraft for reuse in the Artemis II mission.

The Artemis II non-core avionics will be removed from the Artemis I spacecraft, refurbished, and delivered to KSC in the summer of 2022 for installation into the CM-2. For future missions, which are provided under the Orion Production and Sustainment (OPOC) contract, re-use of components is planned to reduce assembly costs of subsequent Orion builds. All new build non-core avionics for the Artemis II spacecraft will be delivered by May 2022 and all core avionics were delivered by January 2022.

Artemis II CM functional tests will be performed April thru June 2022. Following installation of the refurbished non-core avionics into the CM, the Artemis II heatshield will be installed in September 2022 (assuming NET May 2022 Artemis I launch). The Artemis II docking camera and translational hand controllers will be delivered in September 2022 for installation in the CM to support proximity operations activities planned for the Artemis II mission.

Orion completed Artemis II CMA wire harness and subsystem installations in October 2021, the final step prior to mating with the ESM. ESM-2 was delivered to KSC in the same month. The Artemis II ESM and CMA have been mated to form the Service Module (SM). After mating, the SM will undergo clean room operations for ECLSS welding, followed by proof pressure and leak tests, which will be completed by October 2022 in preparation for mating with the CM to form the Artemis II CSM.

Fabrication, assembly, integration and testing of the Artemis II LAS is continuing in FY 2022. The Launch Abort System Facility (LASF) was turned over for Artemis II LAS processing in October 2021. The LAS forward interstage was shipped in place at the Michoud Assembly Facility (MAF) in the same month. Fabrication of the LAS ogives are underway at MAF. Delivery of the Artemis II LAS's Motor Adapter Truss Assembly (MATA) is planned for April 2022, and all ogives to be delivered to MAF by November 2022. The ogives are protective panels that will shield the crew module from the severe vibrations and sounds it will experience during launch.

Orion will conduct integrated testing of the ECLSS and the Orion Crew Survival System Suit (OCSS) in the Orion Life Support Integration Facility (OLIF) at the NASA Johnson Space Center (JSC) to further validate the performance of these systems in preparation for the crewed Artemis II mission. OLIF testing will take place from July thru October 2022.

Human In The Loop (HITL) testing, which is critical to ensuring that spacecraft system meet human compatibility and safety requirements, will be performed in FY 2022 in support of the Artemis II crewed mission, HITL cabin testing completed in December 2021 and will be followed by HITL testing of displays and controls from August 2022 to April 2023.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

The Orion spacecraft uses a significant amount of software for commanding functions, monitoring, and transmitting data, performing fault detection and response, and other tasks. Testing of the flight software is critical to safety and mission success. Formal release of software build 205 is anticipated and supports ascent/abort scenarios.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Completion of final testing and closeout of the Artemis II CM is expected. Thereafter, the CM will be mated with the Artemis SM to form the CSM.

Artemis II CSM will undergo final assembly, installation, and testing.

Lockheed Martin will complete assembly, integration, and testing of the Artemis II LAS and deliver the system to NASA.

In preparation for Artemis II, Orion will complete OLIF testing of the ECLSS. The program will also complete HITL testing of displays.

Artemis III CM assembly, integration, and testing will continue, with CM readiness mating to the SM later in the year.

The delivery of ESM-3 to KSC is planned for NET February 2023. The Artemis III ESM and CMA will be mated to form the SM and will undergo final installation and testing for the following few months. The SM mating with the CM will form the Artemis III CSM.

Several key functional components to include the RPOD system will be delivered and the initial release of RPOD software will be released. These key components support the planned Initial Power On (IPO) testing of the CM in the O&C for Artemis III. The RPOD system enables rendezvous, proximity operations, docking, as well as undocking operations that will begin with the Artemis III mission. A key high fidelity, Six-Degree-of-Freedom Test System (SDTS) of the RPOD system, complete with docking cameras and sensors, will be conducted at a Lockheed Martin facility in Denver, CO. These tests will demonstrate the safety-critical operation of the RPOD hardware and software in the dynamic proximity operations environment.

Following delivery of the Artemis IV pressure vessel and primary structure parts to KSC, Orion will continue with structural assembly, proof test, and subsystem installations on the CM.

Orion will conduct a preliminary MIR for Artemis IV docking system components.

Delivery of Artemis IV pressure vessel to KSC is anticipated in Q2 FY 2023.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2023 PB Request
System Design Review (SDR)		Aug 2007
Preliminary Design Review (PDR)		Aug 2009
Key Decision Point-A (KDP-A)	Feb 2012	Feb 2012
Resynchronization Review		Jul 2012
KDP-B	Q1 FY 2013	Jan 2013
Delta PDR	Q4 FY 2013	Aug 2014
Exploration Flight Test-1 (EFT-1) Launch	Dec 2014	Dec 2014

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Milestone	Confirmation Baseline Date	FY 2023 PB Request
KDP-C, Project Confirmation	FY 2015	Sep 2015
Critical Design Review (CDR)	Oct 2015	Oct 2015
Ascent Abort-2 (AA-2) Flight Test	FY 2020	Jul 2019
Artemis I Launch Readiness	FY 2018	NET May 2022
Artemis II Launch Readiness	Apr 2023	NET May 2024

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Development Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2015	6,768.4	70%	2022	9,301.2	+37.4%	Artemis II	Apr 2023	NET May 2024	13

The above revised baseline cost and Launch Readiness Date were approved by the Agency Program Management Council per section 103 of the NASA Authorization Act of 2005 (P.L. 109-155)

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)*	Change from Base Year Estimate ($M)
TOTAL:	**6,768.4**	**9,301.2**	**+2,532.8**
Mission Operations	281.6	407.7	+126.1
Program Management	671.5	1,144.3	+472.8
Safety and Mission Assurance	191.4	196.2	+4.8
Spacecraft and Payload	3,205.1	6,003.5	+2,798.4
Systems Engineering and Integration	539.3	772.5	+233.2
Test and Verification	460.6	607.5	+146.9
Other Direct Project Costs	1,418.9	169.5	-1,249.4

Program unallocated future expenses (UFE) was held in "Other" category in the base year estimate and realigned to other elements as the program matured.

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Crew Module	The crew module provides a safe habitat for the crew, as well as storage for consumables and research instruments, and it serves as the docking port for crew transfers.	Provider: JSC Lead Center: JSC Performing Center(s): Ames Research Center (ARC), Glenn Research Center (GRC), JSC, and LaRC Cost Share Partner(s): N/A	N/A
Service Module	The service module, the powerhouse that fuels and propels the Orion spacecraft, will support the Crew Module from launch through separation before reentry.	Provider: ESA Lead Center: GRC Performing Center(s): ARC, GRC, JSC, and LaRC Cost Share Partner(s): ESA	N/A
Launch Abort System	The launch abort system maneuvers the Crew Module to safety in the event of an emergency during launch or climb to orbit.	Provider: JSC Lead Center: LaRC Performing Center(s): JSC, LaRC, and Marshall Space Flight Center (MSFC) Cost Share Partner(s): N/A	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: The Artemis I Orion non-core avionics delivery is delayed. Then: The Artemis II CSM handover date to EGS will be impacted.	Teams are assessing opportunities to streamline the time for non-core avionics recovery and refurbishment following Artemis I launch.
If: Orion suppliers and/or Assembly Integration and Processing work experience delays, Then: Final integration and Orion spacecraft deliveries to Exploration Ground Systems for launch processing could be delayed.	Production efforts have been impacted by the pandemic's direct effect on workforce as well as the workforce changes and attrition experienced in the years since the pandemic started. This has been particularly noticeable in certain high skilled jobs, such as technicians. These same issues impact the Orion's international partners and supply chain flow of parts and materials into the program. To minimize impacts, Orion's integrated teams have adjusted the flow of activities and production/integration shifts to minimize delays in production and the integration critical path flow. The program will continue to reassess activity timing, opportunities to improve integration efficiency, and increased workforce in critical areas to maintain production and integration progress, but workforce and supply chain challenges remain.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Acquisition Strategy

NASA is using a contract with Lockheed Martin Corporation for Orion's design, development, test, and evaluation. The contract was awarded in 2006 and reaffirmed in 2011 as part of reformulating the Orion Crew Exploration Vehicle as the Orion Program. Orion adjusted this contract to meet NASA and the Human Exploration and Operations Mission Directorate (HEOMD), now Explorations Systems Development Mission Directorate (ESDMD), requirements to include the current flight test plan and the Artemis II flight readiness date.

In 2012 NASA signed an implementing arrangement with ESA to provide service modules for the Orion spacecraft for Artemis I and later added Annexes 1 and 2 for ESA to provide the European Service Module (ESM) for Artemis II. Incorporating the partnership with ESA also required a contract modification with Lockheed Martin to integrate the ESA-provided service module with the Lockheed Martin portion of the spacecraft. Lockheed Martin has integrated ESM-1 with CM-1 and performed environmental testing of the integrated spacecraft. Lockheed Martin handed the vehicle over to EGS in January 2021 for ground operations. ESA delivered ESM-2 to NASA on October 14, 2021.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Orion Design and Development, Test and Evaluation (DDT&E)	Lockheed Martin	Littleton, CO

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
System Requirements Review (SRR)	Standing Review Board (SRB)	Mar 2007	To evaluate the program's functional and performance requirements, ensuring proper formulation and correlation with Agency and HEOMD's strategic objectives; assess the credibility of the program's estimated budget and schedule.	Program cleared to proceed to next phase.	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
System Design Review (SDR)	SRB	Aug 2007	To evaluate the proposed program requirements and architecture; allocation of requirements to initial projects; assess the adequacy of project pre-formulation efforts; determine if maturity of the program's definition and plans are enough to begin implementation.	Program cleared to proceed to next phase.	N/A
Preliminary Design Review (PDR)	SRB	Sep 2009	To evaluate completeness and consistency of the program's preliminary design, including its projects meet all requirements with appropriate margins, acceptable risk, and within cost and schedule constraints; determine the program's readiness to proceed with the detailed design phase.	Program cleared to proceed to next phase.	N/A
Resynchronization Review	SRB	Jul 2012	To realign the program's preliminary design to the current Exploration Systems Development (ESD) requirements. NASA policies allow changes to a program's management agreement in response to internal and external events. An amendment to the decision memorandum is signed at the KDP-B review held before PDR if a significant divergence occurs.	Program cleared to proceed to next phase.	N/A

CREW VEHICLE DEVELOPMENT

Formulation	**Development**	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Delta PDR	SRB	Aug 2014	To update the program's preliminary design; ensure completeness and consistency; determine the program's readiness to proceed with the detailed design phase.	Program cleared to proceed to next phase.	N/A
Critical Design Review (CDR)	SRB	Oct 2015	To evaluate the integrity of the program integrated design, including its projects and ground systems, its ability to meet mission requirements with appropriate margins and acceptable risk, and that it is planned within cost and schedule constraints; determine if the integrated design is appropriately mature to continue with the final design and fabrication phase for Exploration Mission (EM)-1.	Program cleared to proceed to next phase.	N/A
ESM CDR	SRB	Oct 2016	To evaluate the integrity of the program integrated design, including its projects and ground systems, its ability to meet mission requirements with appropriate margins and acceptable risk, and that it is planned within cost and schedule constraints; determine if the integrated design is appropriately mature to continue with the final design and fabrication phase for EM-1.	Program cleared to proceed to next phase.	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Critical Integration Review (CIR) / System Integration Review (SIR)	N/A	Nov 2016	To evaluate the readiness of the program, including its projects and supporting infrastructure, to begin system Assembly, Integration, and Testing (AI&T) with acceptable risk, and within cost and schedule constraints.	Program cleared to proceed to next phase.	N/A
Artemis II CDR	Independent Assessment (IA) / Independent Review Team (IRT)	Dec 2018	To evaluate the integrity of the program integrated design, including its projects and ground systems, its ability to meet mission requirements with appropriate margins and acceptable risk, and that it is planned within cost and schedule constraints; determine if the integrated design is appropriately mature to continue with the final design and fabrication phase for EM-2.	Program cleared to proceed to next phase.	N/A
ESD Artemis I Independent Schedule Assessment	Schedule Assessors from Office of the Chief Financial Officer (OCFO)	Jun 2019	Programmatic assessment and analysis of Artemis I schedules across all ESD programs with an emphasis on program performance and risks.	NASA leadership was briefed on Artemis I launch date options.	N/A

CREW VEHICLE DEVELOPMENT

Formulation	**Development**	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Inspector General (IG)	Jul 2020	To examine the Agency's management in tracking, reporting overall cost goals of the Orion Multi-Purpose Crew Vehicle Program,	NASA'S Management of the Orion Multi-Purpose Crew Vehicle Program (IG-20-08) IG made three recommendations to increase the sustainability, accountability, and transparency of the Orion Program as it pursues the goal of landing astronauts on the moon by 2024. These areas covered cost reporting, adjusting production schedules for future missions to align with the Artemis II mission to reduce schedule delays associated with potential rework and improving NASA's management of award fees.	N/A
Performance	Inspector General (IG)	Dec 2020	To address NASA's Aerospace Safety Advisory Panel concerns over the Agency's plans to return-to-the-Moon by 2024.	NASA's Challenges to Safely Return Humans to the Moon by 2024 (IG-21-007) IG identified returning to the Moon as a top management and performance challenge and will continue oversight of NASA's management of the Artemis Campaign and the Agency's human exploration efforts through other audits and reviews.	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	General Accounting Office (GAO)	Dec 2020	To assess the progress the programs are making towards Artemis I with respect to schedule and cost, and the extent to which the programs are positioned to support the planned Artemis flight schedule beyond Artemis I.	GAO made two recommendations to establish baselines ahead of a key design review and improve internal reporting about capability upgrades for human space exploration programs beyond Artemis I. NASA concurred with the recommendations made in this report.	N/A
ESD Enterprise Integration Review (EIR)	Independent Review Team	Jan 2021	To confirm that flight and ground hardware elements, software, support equipment, facilities, and infrastructure are ready to support assembly, integration, test, and mission operations per the planned schedule for Artemis I.	The IRT confirmed the programs are sufficiently mature to proceed for integrated operations	N/A
Docking Capability CDR	IA/IRT	April 2021	To evaluate the integrity of the upgrade's integrated design, including its ability to meet mission requirements with appropriate margins and acceptable risk, and that it is planned within cost and schedule constraints of the broader Orion program; determine if the integrated design is appropriately mature to continue with the final design and fabrication phase for flight on Artemis III.	The docking capability was found to be sufficiently mature to proceed to final design and fabrication; costs were analyzed as part of the Orion program Joint Cost and Schedule Confidence Level analysis and reported as part of the Orion program re-baseline.	N/A
Performance	Inspector General (IG)	Apr 2021	To provide an update on the NASA 2020 Artemis Plan.	Artemis Status Update (IG-21-018) - IG will continue to monitor the Agency's efforts towards achieving 2020 Artemis Plan.	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	General Accounting Office (GAO)	May 2021	To assess NASA's ability to accomplish the March 2019 White House direction to accelerate its plans for a lunar landing by four years to 2024.	Significant Work Remains, Underscoring Challenges to Achieving Moon Landing in 2024 (GAO-21-230) - GAO made four recommendations, including that NASA document the process for determining key programmatic and technical tools for the Artemis missions. NASA concurred with three of the recommendations, but not the fourth, which related to the costs included in a lunar rover's cost estimate.	N/A
System Integration Review (SIR)	IA/IRT	May 2021	To assess risks and plans for starting integration of all hardware into the structure to build up the flight vehicle.	The IRT reviewed and approved (technical and programmatic products) for the project to proceed to Phase D.	N/A
KDP-D	IA/IRT	Aug 2021	To assess system assembly, integration, and test; verification/certification; prelaunch activities; launch; and checkout.	The IRT reviewed and granted Orion to proceed with re-baseline cost and schedule.	N/A
Performance	Inspector General	Nov 2021	To assess the Artemis campaign’s schedule and projected costs as well as how the Agency’s acquisition and programmatic approaches facilitate landing astronauts on the Moon.	NASA's Management of the Artemis Missions (IG-22-003) - IG will continue to monitor acquisition and programmatic approach for Artemis Missions.	N/A

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	General Accounting Office (GAO)	Mar 2022	To update NASA's progress and challenges in working towards the first three Artemis missions.	Moon Landing Plans Are Advancing but Challenges Remain (GAO-22-105533) - GAO restated its 10 previous recommendations related to improving NASA's management of its Artemis efforts and related programs. NASA generally agreed with these recommendations and plans to take steps to implement them.	N/A
Operational Readiness Review/ Flight Readiness Review (ORR/FRR) for Artemis II	IA/IRT	NET March 2024	To evaluate the readiness of the project to operate the flight system and associated ground system; and support systems for safe and successful launch and flight/mission.	N/A	N/A
Launch Readiness Date/Initial Operations Capability (LRD/IOC) for Artemis II	IA/IRT	NET May 2024	To assess all capabilities of the vehicle to support the readiness to launch.	N/A	N/A

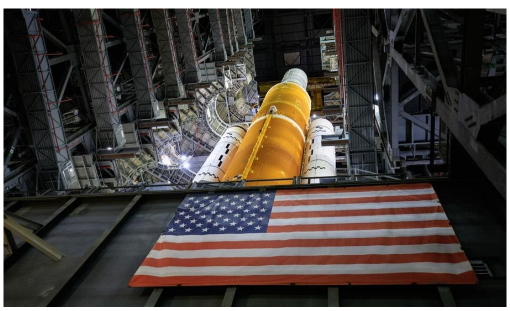
SPACE LAUNCH SYSTEM

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Launch Vehicle Development	2,488.4	2,414.0	**2,505.7**	2,455.8	2,393.2	2,234.4	1,832.7
SLS Program Integration and Support	66.6	73.0	**74.0**	78.8	91.3	92.0	92.7
Total Budget	**2,555.0**	**2,487.0**	**2,579.8**	**2,534.6**	**2,484.6**	**2,326.5**	**1,925.5**
Change from FY 2022 Budget Request			**92.8**				
Percent change from FY 2022 Budget Request			**3.7%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



NASA's Orion spacecraft is stacked atop the Space Launch System rocket at Kennedy Space Center for the upcoming uncrewed flight test around the Moon. With targeted liftoff in May 2022, the Artemis I flight data will anchor analytical models used for mission-to-mission flight certification as well as models and processes to design and certify future configurations.

NASA continues development of a heavy-lift launch vehicle to deliver crew and large volumes of cargo to deep space. The Space Launch System (SLS) program is preparing to carry humans farther into deep space than ever before.

SLS will play an integral role in the Artemis Campaign as a human-rated launch system intended to deliver the Orion spacecraft with crew beyond low-Earth orbit. This launch system will be used in each of the Artemis missions, beginning with Artemis I, which will launch no earlier than May 2022. The Agency will continue to identify and implement affordability strategies to help SLS become a sustainable exploration capability used by subsequent Artemis missions.

The budget request supports launches at their earliest technically feasible dates. For more information, go to: http://www.nasa.gov/exploration/systems/sls/index.html

Program Elements

SLS PROGRAM INTEGRATION AND SUPPORT

SLS Program Integration and Support activities manage the program interfaces between Orion and Exploration Ground Systems. This effort is critical to ensuring the performance of SLS systems meets technical and safety specifications, and supports programmatic assessments key to achieving integrated technical, cost, and schedule management. In addition, the SLS integration effort is vital to managing interfaces with other Exploration Systems Development Mission Directorate and Space Operations Mission Directorate activities, including strategic studies, feasibility studies, and small-scale research tasks that feed into future human exploration. Coordination and timely integration across the programs are

SPACE LAUNCH SYSTEM

critical to mitigating the impacts of potential design overlaps, schedule disconnects and delays, and cost overruns.

LAUNCH VEHICLE DEVELOPMENT

The Launch Vehicle Development project will develop the SLS launch vehicle to enable deep space exploration and support production and sustainment for flights. See the Launch Vehicle Development section beginning on the next page for additional details.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

FY 2023 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027	BTC	Total
Formulation	2,673.9	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	2,673.9
Development/Implementation	8,491.1	429.3	187.9	**0.0**	0.0	0.0	0.0	0.0	0.0	9,108.3
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2022 MPAR LCC Estimate	**11,165.0**	**429.3**	**187.9**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**11,782.2**
Total Budget	**16,676.5**	**2,488.4**	**2,414.0**	**2,505.7**	**2,455.8**	**2,393.2**	**2,234.4**	**1,832.7**	**0.0**	**33,000.7**
Change from FY 2022 Budget Request				**91.7**						
Percent change from FY 2022 Budget Request				**3.8%**						

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

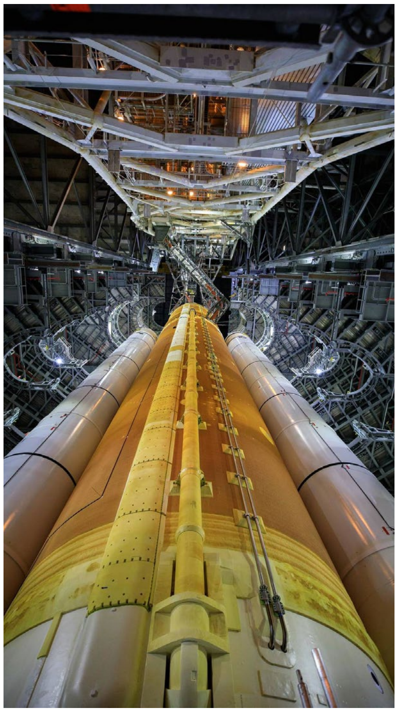
Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The difference between the total budget and the MPAR LCC estimate is the total budget includes content outside of Artemis I and excludes CoF; LCC only includes Artemis I content, including CoF.

With the arrival of the SLS Core Stage at KSC in April 2021, NASA is continuing to assess the schedule and work remaining for the Artemis I mission. NASA Leadership will review the results of these assessments before considering potential updates to the Artemis I and II launch planning dates.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations



SLS rocket for Artemis I inside High Bay 3 of the Vehicle Assembly Building (VAB) at NASA's Kennedy Space Center (KSC) in Florida.

PROJECT PURPOSE

In support of the Artemis mission, the Launch Vehicle Development project will enable deep space exploration with the Space Launch System (SLS) launch vehicle. For the first time since the Apollo program in 1972, American astronauts will explore space beyond low-Earth orbit (LEO) and return to the Moon, reinvigorating America's human exploration of the solar system.

EXPLANATION OF MAJOR CHANGES IN FY 2023

The current Artemis I Launch Readiness Date (LRD) is no earlier than (NET) May 2022. The current LRD for Artemis II is NET May 2024.

NASA is focusing on successful completion of Artemis I and II and preparation required for Artemis III and IV. The first three flights will feature the SLS Block 1 configuration, utilizing a human-rated Interim Cryogenic Propulsion Stage (ICPS). The Budget will be used to continue development of the SLS Block 1B configuration with the Exploration Upper Stage (EUS) for a first flight on Artemis IV. This block evolution approach focuses NASA and its contractors on successfully delivering and flying the Block 1 SLS before folding in the additional Block 1B developments.

PROJECT PARAMETERS

The primary components of the SLS include the Launch Vehicle Stage Adapter (LVSA), the ICPS, the core stage and avionics, two five-segment solid rocket boosters, and four RS-25 engines.

The SLS core stage is over 200 feet tall, and atop it sits the LVSA, which connects the ICPS and core stage. The Launch Vehicle Stage Adapter (LVSA) provides structural support for launch and separation loads and protects propulsion system electrical components. The core stage contains five primary subcomponents, including the forward skirt, liquid oxygen tank, intertank, liquid hydrogen tank, and engine section. The engine section is the attach point for the four RS-25 engines, which combined with the boosters will produce maximum thrust of 8.8 million pounds. On each side of the core stage, the five-segment solid rocket boosters will stand 17 stories tall and burn five tons of propellant per second. The boosters connect via the intertank and engine section attach points and will augment initial thrust for the first two minutes of flight.

The Launch Vehicle Development project leverages hardware designed for heritage programs, including adapted and refurbished Space Shuttle RS-25 main engines, five-segment Shuttle-derived solid rocket boosters, and an ICPS derived from the Delta cryogenic second stage. The program benefits from

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

NASA's over half-century of experience and knowledge of liquid oxygen and hydrogen heavy-lift vehicles, large solid rocket motors, and advances in technology and manufacturing practices, such as friction stir welding. The SLS rocket will generate a total thrust at liftoff greater than that of the Saturn V rocked used in the Apollo program.

The launch vehicle development follows a block evolution framework where the core stage will serve as the common component in all future configurations. The Block 1 configuration, which is the configuration for Artemis I, stands at 322 feet and features a lift capability of over 27 metric tons to translunar injection for Moon missions. With this performance, Block 1 will be able to send the Orion spacecraft towards the Moon. This SLS configuration will allow Orion to demonstrate deep space technologies and hardware required for Earth-independent missions.

The planned evolution of the architecture to the Block 1B configuration will include an Exploration Upper Stage (EUS), associated Universal Stage Adapter (USA) and Payload Adapter (PLA) to support Co-Manifested Payloads (CPLs). This Block 1B configuration will be capable of delivering at least 37.3 metric tons of net payloads (Orion and up to 10.3 metric tons of additional payloads) to Trans-Lunar Injection (TLI) on crewed missions

ACHIEVEMENTS IN FY 2021

Artemis I fully integrated core stage testing, also known as the Green Run, was completed in FY 2021. The test series ended with a hot-fire on March 18, 2021. This final hot-fire test was critical to ensuring all core stage components are ready for vehicle certification and final integration at Kennedy Space Center (KSC). After Green Run, the core stage flight article, which required very little refurbishment, was removed from the test stand at the Stennis Space Center and transported to KSC. At KSC, the core stage was successfully integrated with the two solid rocket boosters, the LVSA, and the ICPS. The ICPS was mated to the stack in July, and an Umbilical Release and Retract Test was completed in September.

Also, SLS completed a series of design certification review periods that concluded with a successful Design Certification Review (DCR) process in January 2021 and concluded in September 2021. This multiple segment process certifies the vehicle in preparation for the Artemis I Flight Readiness Review.

Hardware production continued on Artemis II, the first crewed flight of SLS, at Michoud Assembly Facility (MAF) in New Orleans. Hardware fabrication of key Core Stage components included the forward skirt (completed in February 2021), intertank (completed at MAF in March 2021), liquid oxygen tank (completed in April 2021), liquid hydrogen tank, and engine section.

SLS continued to mature the capabilities of the more powerful Block 1B (B1B) vehicle. An Independent Review Team (IRT) completed its initial review of the B1B Exploration Upper Stage (EUS) and associated activities during the summer and fall of 2021, recommending that EUS move into Key Decision Point Phase C, which is the final design and fabrication stage. The IRT has committed to remain engaged with the program for the upcoming Critical Design Review (CDR), ensuring continuous independent assessment of the B1B upgrade.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

WORK IN PROGRESS IN FY 2022

The final stacking of the SLS elements for Artemis I was completed on October 11, 2021, when the Orion Stage Adaptor (OSA) was mated to the stack. The OSA also contained 10 secondary payloads that will be released after the ICPS separates from the Orion spacecraft. The Orion spacecraft was mated to the OSA, completing stacking of all components for the Artemis I mission.

Hardware production continues for Artemis II, the first crewed flight of SLS with fabrication and outfitting of the liquid oxygen tank, liquid hydrogen tank, and engine section at MAF; as well as the completion of the first major join to create the forward section (forward skirt, liquid oxygen tank and intertank). Teledyne Brown Engineering has welded all LVSA panel sections and applied its thermal protection system, and United Launch Alliance has shipped the second ICPS from Decatur, AL, to KSC. SLS is also continuing Artemis II hardware completion with production of the OSA, delivery of four RS-25 engines to MAF for integration, and completion of booster forward and aft assemblies. The program completed the first flight readiness analysis cycle for Artemis II. With the completion of the liquid hydrogen tank, the next major join will occur with the mate of the forward section and hydrogen tank. In addition, the Core Stage Engine Section integration activities continue.

The B1B vehicle will have an internal Boeing review with NASA insight in preparation for a CDR in the summer of 2022. Autonomous Flight Safety System (AFSS) is currently under development by the B1B Development Office to replace the heritage Flight Termination System. These range safety systems are used to destroy the vehicle in the event of a major malfunction. The AFSS will be flown in shadow (monitor only) mode on Artemis III and fully operational on Artemis IV. It replaces the old system, which will no longer be supported by the United States Space Force.

Artemis III hardware production will continue, including the Artemis III OSA, ICPS-3, and LVSA for this mission. The panels for the LVSA will be welded together. SLS will initiate contract actions for the Stages Production and Evolution Contract (SPEC) in 2022. In November 2021, SLS awarded the Booster Production and Operation Control (BPOC) contract. This includes production and operations for boosters for Artemis IV-VIII and design, development, test, and evaluation of a booster flight set as part of Booster Obsolescence and Life Extension (BOLE) for Artemis IX.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

SLS will complete core stage two final assembly and integration with delivery to Exploration Ground Systems (EGS) at KSC for stacking and integration. Artemis II will be the first crewed launch of the SLS rocket and the Orion spacecraft.

Artemis III hardware production will continue, including the Artemis III OSA, ICPS-3, core stage components and launch vehicle stage adaptor for this mission. Artemis IV hardware production will continue.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Schedule Commitments/Key Milestones

Milestone	Confirmation Baseline Date	FY 2023 PB Request
Key Decision Point-A (KDP-A)	Nov 2011	Nov 2011
Formulation Authorization	May 2012	May 2012
System Requirements Review (SRR)	May 2012	May 2012
KDP-B Agency Project Management Council (APMC)	Jul 2012	Jul 2012
Preliminary Design Review (PDR) Board	Jun 2013	Jun 2013
KDP-C APMC	Jan 2014	Jan 2014
Critical Design Review (CDR) Board	Jul 2015	Jul 2015
Design Certification Review	Sep 2017	Sep 2021
Artemis I Launch Readiness*	Nov 2018	NET May 2022

**Currently under review until wet dress rehearsal*

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2015	6,390.4	70%	2022	9,108.3	+42.5%	Artemis I Launch Readiness	Nov 2018	NET May 2022	42

Note: NASA continues to review past reporting, and estimates do not necessarily accurately incorporate actual expenditures to date. Additionally, cost and confidence levels do not reflect the cost impacts of currently anticipated schedule delays. The estimates are expected to increase as NASA assesses the impacts of further delays and updates reporting on expenditures. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**6,390.4**	**9,108.3**	**+2,717.9**
Stages Element	3,138.6	5,183.7	+2,045.1
Liquid Engines Office*	567.3	495.5	-71.8
Booster Element	1,090.3	1,053.3	-37.0
Spacecraft Payload Integration and Evolution (SPIE)	447.1	640.2	+193.1
Other	1,147.1	1,735.6	+588.5

**The Agency Baseline Commitment previously included fixed and shared costs with the RS-25 production restart activity (in the Liquid Engines Office), which supports Artemis I and later missions. SLS removed those costs from the estimate and significantly lowered the Artemis I Liquid Engines Office and Base Year Development Cost Estimate.*

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Booster	Responsible for development, testing, production, and support for the five-segment solid rocket motor to be used on initial capability flights.	Provider: Marshall Space Flight Center (MSFC) Lead Center: MSFC Performing Center(s): MSFC Cost Share Partner(s): N/A	N/A
Engines	Responsible for development and/or testing, production, and support for both core stage (RS-25) and upper stage liquid engines.	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC; SSC Cost Share Partner(s): N/A	N/A
Block 1B Development Office	Responsible for development, testing, and production of the initial Exploration Upper Stage, as well as development for the Autonomous Flight Safety System (AFSS).	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC/MAF; SSC Cost Share Partner(s): N/A	N/A

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Stages	Responsible for development, testing, production, and support of hardware elements, including core and upper stages, liquid engine integration, and avionics integration.	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC/MAF; SSC Cost Share Partner(s): N/A	N/A
Spacecraft Payloads and Integration	Responsible for development, testing, production, and support of hardware elements for integrating the Orion spacecraft and payloads onto SLS, including the ICPS, OSA, LVSA, USA, and payload fairings.	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC, Langley Research Center (LaRC), Glenn Research Center (GRC), and KSC Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement (Ranked in Sequential order)	Mitigation
If: SLS suppliers and/or Assembly Integration and Processing work experience delays, Then: Final integration and SLS Launch Vehicle deliveries to Exploration Ground Systems for launch processing could be delayed.	Production efforts have been impacted by the pandemic's direct effect on workforce as well as the workforce changes and attrition experienced in the years since the pandemic started. This has been particularly noticeable in certain high skilled jobs, such as technicians. These same issues impact the SLS's supply chain flow of parts and materials into the program. To minimize impacts, SLS's teams have adjusted the flow of activities and production/integration shifts to minimize delays in production and the integration critical path flow. The program will continue to reassess activity timing, opportunities to improve integration efficiency, and increased workforce in critical areas to maintain production and integration progress, but workforce and supply chain challenges remain.

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Acquisition Strategy

MAJOR CONTRACTS/AWARDS

Procurement for SLS launch vehicle development meets the Agency's requirement to provide an evolvable vehicle within a schedule that supports various mission requirements. Procurements include use of existing assets to expedite development and further development of technologies and future competitions for advanced systems and key technology areas specific to SLS vehicle needs.

Element	Vendor	Location (of work performance)
Universal Stage Adaptor	Dynetics, Inc.	Huntsville, AL
Launch Vehicle Stage Adaptor	Teledyne Brown Engineering, Inc.	Huntsville, AL
Boosters	Northrop Grumman Innovation Systems	Magna, UT
Core Stage Engine	Aerojet Rocketdyne	Desoto Park, CA; SSC
ICPS	United Launch Alliance under contract to Boeing Aerospace	Huntsville, AL
Stages (Core and Upper)	Boeing Aerospace	New Orleans, LA
Upper Stage Engines	Aerojet Rocketdyne	West Palm Beach, FL

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Preliminary Design Review (PDR)	SRB	Aug 2013	To evaluate the completeness and consistency of the planning, technical, cost, and schedule baselines developed during formulation; assess compliance of the preliminary design with applicable requirements; and determine if the project is sufficiently mature to begin Phase C.	The SRB evaluated the project and determined the project is sufficiently mature to begin Phase C and begin final design and fabrication.	N/A

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Critical Design Review (CDR)	SRB	Jul 2015	To evaluate the integrity of the project design and its ability to meet mission requirements with appropriate margins and acceptable risk within defined project constraints, including available resources. To determine if the design is appropriately mature to continue with the final design and fabrication phase.	The SRB evaluated the project and determined the project is sufficiently mature to progress to major manufacturing, assembly, and integration.	N/A
Exploration Systems Development (ESD) Artemis I Independent Schedule Assessment	Schedule Assessors from Office of the Chief Financial Officer (OCFO)	Jun 2019	Programmatic assessment and analysis of Artemis I schedules and schedule risk across all ESD programs with an emphasis on program performance and risks.	NASA leadership was briefed on Artemis I launch date options.	N/A
Performance	Inspector General (IG)	Mar 2020	To update the status of Core Stages development and examine the remaining major SLS elements and corresponding prime contracts to determine the extent to which the SLS is meeting Artemis 1 cost and schedule goals, that NASA is tracking and appropriately reporting overall cost and schedule goals, and SLS is managing cost and schedule for key contracts.	NASA's Management of Space Launch System Program Costs and Contracts (IG-20-012) NASA concurred with IG recommendations including reviewing Human Exploration and Operations Mission Directorate and program management policies, procedures, and ABC reporting processes; and improvements to contract management, cost accounting and performance monitoring.	N/A

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
ESD Artemis I Re-baseline	Independent Review Team (IRT)	Apr 2020	Programmatic assessment and analysis of Artemis I schedule and schedule risks of Artemis I launch date and JCL.	Established revised baseline and launch readiness date.	N/A
Performance	Inspector General (IG)	Dec 2020	To address NASA's Aerospace Safety Advisory Panel concerns over the Agency’s plans to return-to-the-Moon by 2024.	NASA's Challenges to Safely Return Humans to the Moon by 2024 (IG-21-007) IG identified returning to the Moon as a top management and performance challenge and will continue oversight of NASA’s management of the Artemis campaign and the Agency’s human exploration efforts through other audits and reviews.	N/A
Performance	General Accounting Office (GAO)	Dec 2020	To assess the progress the programs are making towards Artemis I with respect to schedule and cost, and the extent to which the programs are positioned to support the planned Artemis flight schedule beyond Artemis I.	GAO made two recommendations to establish baselines ahead of a key design review and improve internal reporting about capability upgrades for human space exploration programs beyond Artemis I. NASA concurred with the recommendations made in this report.	N/A

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
ESD Enterprise Integration Review (EIR)	IRT	Jan 2021	To confirm that flight and ground hardware elements, software, support equipment, facilities and infrastructure are ready to support assembly, integration, test, and mission operations per the planned schedule for Artemis I.	The IRT confirmed the programs are sufficiently mature to proceed for integrated operations.	N/A
Performance	Inspector General (IG)	Apr 2021	To provide an update on the NASA 2020 Artemis Plan.	Artemis Status Update (IG-21-018) - IG will continue to monitor the Agency's efforts towards achieving 2020 Artemis Plan.	N/A
Performance	General Accounting Office (GAO)	May 2021	To assess NASA's ability to accomplish the March 2019 White House direction to accelerate its plans for a lunar landing by four years to 2024.	Significant Work Remains, Underscoring Challenges to Achieving Moon Landing in 2024 (GAO-21-230) - GAO made four recommendations, including that NASA document the process for determining key programmatic and technical tools for the Artemis missions. NASA concurred with three of the recommendations, but not the fourth, which related to the costs included in a lunar rover's cost estimate.	N/A

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Design Certification Review (DCR)	SLS IRT	Sep 2021	To certify the implemented design complies with applicable requirements and necessary verification activities are satisfactorily completed.	This multiple segment process certified the vehicle in preparation for the Artemis I Flight Readiness Review.	N/A
Performance	Inspector General	Nov 2021	To assess the Artemis Campaign's schedule and projected costs as well as how the Agency's acquisition and programmatic approaches facilitate landing astronauts on the Moon.	NASA's Management of the Artemis Missions (IG-22-003) - IG will continue to monitor acquisition and programmatic approach for Artemis Missions.	N/A
Performance	General Accounting Office (GAO)	Mar 2022	To update NASA's progress and challenges in working towards the first three Artemis missions.	Moon Landing Plans Are Advancing but Challenges Remain (GAO-22-105533) - GAO restated its 10 previous recommendations related to improving NASA's management of its Artemis efforts and related programs. NASA generally agreed with these recommendations and plans to take steps to implement them.	N/A
Operational Readiness Review/ Flight Readiness Review (ORR/FRR) for Artemis I	Independent Assessments (IA)/IRT	NET Apr 2022	To evaluate the readiness of the project to operate the flight system and associated ground system; and support systems for safe and successful launch and flight/mission.	N/A	N/A

LAUNCH VEHICLE DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Launch Readiness Date/Initial Operations Capability (LRD/IOC) for Artemis I	IA/IRT	NET May 2022	To assess all capabilities of the vehicle to support the readiness to launch.	N/A	N/A

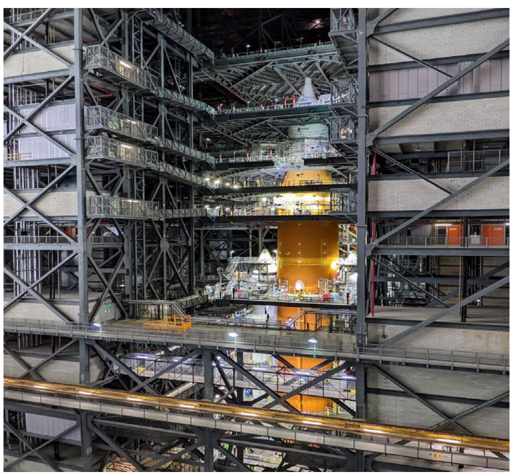
EXPLORATION GROUND SYSTEMS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**580.0**	**590.0**	**749.9**	**664.2**	**510.8**	**467.2**	**432.3**
Change from FY 2022 Budget Request			**159.9**				
Percent change from FY 2022 Budget Request			**27.1%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



NASA's Space Launch System and Orion Spacecraft in High Bay 3 of the Vehicle Assembly Building.

The Exploration Ground Systems (EGS) program will play an integral role in the Artemis missions by enabling integration, processing, and launch of the Space Launch System (SLS) and Orion spacecraft. EGS is making all required facility and ground support equipment modifications at Kennedy Space Center (KSC) to enable assembly, test, and launch of SLS and Orion, along with landing and recovery activities of the Orion spacecraft flight elements in support of Artemis missions. EGS is also modernizing communication and control systems to support these activities.

The EGS program, based at KSC, develops and operates the systems and facilities necessary to process, assemble, transport, and launch spacecraft and rockets. EGS's mission is to enable the Center to handle future Artemis missions.

EGS is upgrading the launch pad, Launch Complex-39B (LC-39B), crawler-transporters, Vehicle Assembly Building (VAB), Launch Control Center's Young-Crippen Firing Room 1, mobile launcher-1 (ML-1), and other ground facilities for crewed operations.

For more information, go to: https://www.nasa.gov/exploration/systems/ground/index.html

Program Elements

EGS PROGRAM INTEGRATION AND SUPPORT

EGS Program integration and support activities manage program interfaces between the SLS and Orion. This effort is critical to ensuring ground systems' performance meets technical and safety specifications and supports the programmatic assessments key to achieving integrated technical, cost, and schedule management. In addition, the EGS integration effort is vital to managing interfaces with other Exploration Systems Development Mission Directorate and Space Operations Mission Directorate activities, including

EXPLORATION GROUND SYSTEMS

strategic studies, feasibility studies, and small-scale research tasks that feed into future human exploration. Coordination and timely integration across the three programs is aimed at mitigating the impacts of potential design overlaps, schedule disconnects and delays, and cost overruns.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

EGS Development is developing necessary ground systems as well as refurbishing and upgrading infrastructure and facilities required for assembly, test, and launch of SLS and Orion, along with landing and recovery activities of Orion. This includes LC-39B, the VAB, the ML, and other smaller facilities. See the Exploration Ground Systems Development section beginning on the following page for additional details.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

FY 2023 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027	BTC	Total
Formulation	974.7	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	974.7
Development/Implementation	2,289.7	200.9	101.9	**0.0**	0.0	0.0	0.0	0.0	0.0	2,592.5
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2022 MPAR LCC Estimate	**3,264.5**	**200.9**	**101.9**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**3,567.3**
Total Budget	**4,168.0**	**569.2**	**585.3**	**747.3**	**660.0**	**503.8**	**460.0**	**425.0**	**0.0**	**8,118.6**
Change from FY 2022 Budget Request				**162.0**						
Percent change from FY 2022 Budget Request				**27.7%**						

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The difference between the total budget and the MPAR LCC estimate is the total budget includes content outside of Artemis I and excludes CoF; LCC only includes Artemis I content, including CoF.

With the arrival of the SLS Core Stage at KSC in April 2021, NASA is continuing to assess the schedule and work remaining for the Artemis I mission. NASA Leadership will review the results of these assessments before considering potential updates to the Artemis I and II launch planning dates.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Shown here is the fully assembled Space Launch System rocket and Orion Spacecraft in High Bay 3 of the Vehicle Assembly Building at NASA's Kennedy Space Center in Florida.

PROJECT PURPOSE

Exploration Ground Systems (EGS) is preparing to launch the Space Launch System (SLS) and Orion spacecraft in support of the Artemis missions. EGS is developing the necessary ground systems while refurbishing and upgrading infrastructure and facilities required for assembly, test, and launch of SLS and Orion, along with the landing and recovery activities of Orion. This includes the pad, known as Launch Complex-39B (LC-39B), the Vehicle Assembly Building (VAB), mobile launchers 1 and 2 (ML-1, ML-2), and other smaller facilities to evolve from a Space Shuttle focus to supporting Artemis missions. The modernization efforts maintain flexibility for LC-39B and the VAB to accommodate other potential users and commercial partners, though no other users have been identified to date. Following the Artemis I launch of the first SLS and Orion, the ML-1, VAB, and LC-39B will undergo additional modifications to accommodate crewed flight. Kennedy Space Center (KSC) has more than 50 years serving as our Nation's gateway to exploring the universe. Using the knowledge and assets of NASA's successful spacefaring past, the EGS Program is helping to build a successful future for human spaceflight.

For more information, go to: http://go.nasa.gov/groundsystems

EXPLANATION OF MAJOR CHANGES IN FY 2023

The current Artemis I target Launch Readiness Date (LRD) is no earlier than (NET) May 2022 (currently being assessed, pending final integration and test). The current target LRD for Artemis II is NET May 2024. Due to poorly-defined requirements, poor contractor performance, and increased material costs, additional funding has been added to the budget to support continued development and construction.

PROJECT PARAMETERS

EGS is focusing on the equipment, management, and operations required to safely mate Orion with the SLS, move the integrated SLS/Orion stack to the launch pad, and successfully launch it into space. The work entails use of many of the facilities unique to KSC, such as the 52-story VAB and LC-39B launch complex. For the Artemis missions, the EGS team is developing procedures and protocols to process the spacecraft, the rocket elements, and the launch abort system before assembly into an integrated vehicle. Additional ground system work required to launch astronauts into space on Artemis II includes modifying the ML-1 and crawler-transporters, preparing LC-39B at KSC, and modernizing computers, software, tracking systems, and other network communications.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

The ML-1 is the ground structure used to assemble, process, and launch the SLS rocket and Orion spacecraft from LC-39B at KSC. ML-1 consists of a two-story base that is the platform for the rocket and a tower equipped with a number of connection lines, called umbilicals, and launch accessories that will provide SLS and Orion with power, communications, coolant, fuel, and stabilization prior to launch. The tower also contains a walkway for personnel and equipment entering the crew module during launch preparations. ML-1 will support the Agency's Artemis I, II, and III launches.

ML-2 is the ground platform structure that will launch SLS Block 1B configurations into lunar orbit. ML-2 is the primary interface between the ground launch control system and the SLS rocket and Orion spacecraft flight hardware. The ML-2 construction contract was awarded in July 2019 and is aligned to support the first launch of a Block 1B.

Machines called crawler-transporters have carried the load of taking rockets and spacecraft to the launch pad for more than 50 years at KSC. Crawler-Transporter 2 (CT-2) will be used for launches of SLS and Orion.

ACHIEVEMENTS IN FY 2021

Significant Artemis I milestones were completed in FY 2021, such as the booster stack, core stage mate, Orion to SLS Integration, and the Integrated Vehicle Tests. In addition, significant development progress was made in support of future Artemis crewed missions, such as the Preliminary Design Review for the ML-2 and progress on the Emergency Egress System.

EGS completed software development efforts and Multi-Element Verification and Validation (MEVV) of the ground systems in support of Artemis I. Spacecraft processing operations for Orion took place at the Multi-Payload Processing Facility (MPPF) and Launch Abort System Facility (LASF), followed by SLS flight hardware assembly and SLS/Orion integration and testing at the VAB in support of the Artemis I mission.

The integrated recovery team of NASA, EGS, Lockheed Martin and the Department of Defense (DoD) team, along with additional contractor support, conducted Underway Recovery Test-8 (URT-8) in the Pacific coast of California to ensure the safe recovery of the Orion crew module after the Artemis I mission.

The Spacecraft Command and Control System (SCCS) completed development and verification and validation activities and is supporting processing operations at KSC.

The program completed a two-step PDR for the ML-2, which demonstrated the preliminary design met all system requirements and establishes the basis for proceeding to Critical Design Review (CDR). PDR Step 1, which covered technical requirements and readiness, was completed in March 2021. Results from PDR Step 2, which covers programmatic readiness and results in the establishment of an Agency Baseline Commitment, will be reviewed for final approval at KDP-C in 2022.

The EGS team made progress on a new Emergency Egress System (EES) for LC-39B, an emergency system where flight or ground crew could board a basket with a braking system at the crew access level of the ML-1. The crew would ride the basket down a cable and come to a stop near a bunker to the west of

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

the pad surface, providing quick escape in the unlikely event of an emergency. Construction will be complete in time to support crewed Artemis missions.

The program continued construction activities of the Liquid Hydrogen (LH2) Sphere at LC-39B. The project involved the integration of a new 1.4 million gallon, LH2 storage sphere into the existing LC-39B system. The new LH2 Sphere, in addition to the current LH2 Sphere, will supply LH2 for Artemis II and beyond. The larger tank will allow NASA to attempt SLS launches on three consecutive days, instead of opportunities of two out of three days, in the event of a scrub. The newer technology reduces liquid hydrogen burn-off, allowing more launch attempts before having to refill the larger tank. Construction began in 2019 and will be complete to support Artemis II.

The EGS Program Artemis II Checkpoint I was conducted in August 2021. The review was successful, and all board members concurred that EGS demonstrated readiness in support of the Artemis II Mission.

WORK IN PROGRESS IN FY 2022

In support of Artemis I and II, EGS will complete key milestones in FY 2022. For Artemis I, EGS will perform Wet Dress Rehearsal (WDR), perform final closeouts, and launch the first Artemis mission. In preparation for Artemis II and future crewed missions, EGS will utilize the modification period between launches to complete critical modifications, upgrades, and developments to the launch pad, VAB, and ML-1.

The program completed URT-9 in November 2021. The purpose of URT-9 was to certify the recovery personnel and related on-shore mission interfaces who will be responsible for Artemis I mission recovery operations.

EGS will complete the Artemis I WDR and perform final closeouts in spring of 2022. Shortly after, pad operations and launch countdown will begin, and EGS will launch the first Artemis mission, followed by landing and recovery operations. The current Artemis I target LRD is currently planned for NET May 2022 (currently being assessed, pending final integration and test).

Concurrent with first time processing and launch of Artemis I, EGS will continue development work for the upgrades and modifications to the launch pad, VAB and ML-1 in support of Artemis II, the first crewed mission, and future missions. The EES Conveyance Modifications Construction Contract for ML-1 and LC-39B will provide emergency exit from the launch vehicle. The project began off-line fabrication in October 2021 and is expected to begin on-site field installation in the fourth quarter of FY 2022.

In FY 2022, EGS will continue the Emergency Egress System for and begin the hardware pre-fabrication modifications and construction on ML-1. The program will also complete construction of LC-39's Liquid Hydrogen Sphere and begin verification and validation certification.

EGS will continue fabrication of Environmental Control System (ECS) in the VAB and begin upgrades at LC-39B to support future Artemis missions and continue upgrades at the Compressor Converter Facility. The program will also continue design of the liquid Nitrogen RL-10 Chilldown system at LC-39B.

The ML-2 Programmatic PDR was held in December 2021 along with a review by an Independent Review Team (IRT). In late FY 2022, ML-2 will complete the Critical Design Review and begin the construction phase of the project.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

The design for the Payload Enclosed Access Room (PEAR) will begin in FY 2022. The PEAR cleanroom will support cargo payloads future missions.

EGS will begin the construction for Vehicle Assembly Building (VAB) High Bay (HB) 3 platform modifications in FY 2022. The HB3 platforms will be utilized for processing and stacking the Exploration Upper Stage (EUS) and Interstage, which will support future crewed Artemis missions.

EGS will start performing validation of Crew Transportation Vehicle in September 2022.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

The program will complete most Artemis II development efforts discussed above to support the Artemis II launch in FY 2024.

The integrated recovery team of NASA, EGS, Lockheed Martin, and the DoD, along with additional contractor support, will conduct URT-10 in the fall of 2022 in the Pacific coast of San Diego California to ensure safe recovery of the Orion crew module for future Artemis missions. URT-10 will be the first underway test to support Artemis II's crewed mission. This test will include day and night recovery testing.

Other major construction projects, such as the construction for the Liquid Nitrogen Infrastructure Update, VAB HB4, and VAB Payload Enclosed Access Room (PEAR) will begin in FY 2023. These efforts will support future crewed Artemis missions by upgrading the Liquid Nitrogen capabilities for quicker turnarounds for scrubbed launches, modifying the VAB HB4 platforms to support processing and stacking the SLS B1B vehicle configuration, and providing the PEAR cleanroom that will support cargo payloads on future missions.

Schedule Commitments/Key Milestones

Milestone	Confirmation Baseline Date	FY 2023 PB Request
Key Decision Point-A (KDP-A)	Feb 2012	Feb 2012
Formulation Authorization	Apr 2012	Apr 2012
Systems Requirements Review (SRR) / System Design Review (SDR)	Aug 2012	Aug 2012
KDP-B Agency Project Management Council (APMC)	Nov 2012	Nov 2012
Preliminary Design Review (PDR) Board	Mar 2014	Mar 2014
KDP-C APMC	May 2014	May 2014
Critical Design Review (CDR) Board	Dec 2015	Dec 2015
System Integration Review (SIR)	Apr 2018	Jun 2018

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Milestone	Confirmation Baseline Date	FY 2023 PB Request
Operational Readiness Review / Flight Readiness Review (FRR)	Jul 2019	Jul 2019
Artemis I Launch Readiness	Nov 2018	NET May 2022 (under assessment)
Mobile Launcher 2 PDR (Technical)	Mar 2021	Mar 2021
Mobile Launcher 2 PDR (Programmatic)	Jul 2021	Dec 2021

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2015	1,843.5	80%	2022	2,592.5	40.6%	Artemis I Readiness	Nov 2018	NET May 2022	42

NASA continues to review past reporting, and estimates do not necessarily accurately incorporate actual expenditures to date. Additionally, cost and confidence levels do not reflect the cost impacts of currently anticipated schedule delays. The estimates are expected to increase as NASA assesses the impacts of further delays and updates reporting on expenditures. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)*	Change from Base Year Estimate ($M)
TOTAL	**1,843.5**	**2,592.5**	**+749.0**
Mobile Launcher	213.1	501.4	+288.3
LC-39B Pad	77.5	48.1	-29.4
VAB	92.7	42.1	-50.6
Command, Control, and Communications	198.0	544.5	+346.5
Offline Processing and	110.2	143.5	+33.3

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)*	Change from Base Year Estimate ($M)
Infrastructure			
Other	1,152.0	1,313.0	+161.0

Other includes Crawler Transporter, Launch Equipment Test Facility, Integrated Operations, Program Management, Logistics, Safety and Mission Assurance (S&MA), Integrated and Offline Operations, Construction of Facility and Systems Engineering and Integration (SE&I).

The Agency Baseline Commitment for LC-39B, VAB, and Offline Processing and Infrastructure previously integrated Operations cost which support Artemis I and later missions. EGS realigned those costs from each element and moved those costs to the Other element, significantly lowering those elements' Current Year Development Cost Estimate. In addition, the program removed $27 million in costs for the VAB Utility Annex from the VAB element estimate. Those costs were covered by Center Management and Operations as that work was determined to benefit all programs at KSC.

Project Management & Commitments

EGS balances customer requirements among SLS, Orion, and other Government and commercial users. EGS is developing ground systems infrastructure necessary to assemble, test, and launch SLS and Orion, as well as land and recover Orion flight elements.

Element	Description	Provider Details	Change from Baseline
Ground Systems Implementation (GSI)	GSI is responsible for the design, development, build, hardware/software integration, verification and validation, test, and transition to operations for Program facility systems and Ground Support Equipment (GSE).	Provider: KSC Lead Center: KSC Performing Center(s): Ames Research Center (ARC) Cost Share Partner(s): N/A	N/A
Operations and Test Management (O&TM)	O&TM is responsible for conducting overall planning and execution of both flight hardware and ground systems processing activities.	Provider: KSC Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Command, Control, Communication (C3)	C3 is responsible for development, operation, and sustainment of End-to-End Command and Control and Communications services.	Provider: KSC Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Program Management Team (PMT)	PMT includes project management, safety and mission assurance, logistics, systems engineering, utilities and facility operations, and maintenance.	Provider: KSC Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: The modifications to ML-1 are not completed in the planned 18-month window between Artemis I and Artemis II, Then: There is a possibility that the Emergency Egress System (EES) construction will not be completed in time to allow for Verification and Validation (V&V) prior to vehicle processing for Artemis II.	There is a dependency on the ML-1 being available and modifications being completed to complete the construction and activation of the EES at the Pad. The dependencies with Artemis II ML-1 modifications may prevent timely installation and testing of the EES with ML-1. Mitigation efforts being pursued include compressing the EES design schedule, compressing the construction schedule, exploring alternate implementation methods, initiating the construction earlier, and/or reducing the overall V&V schedule.
If: The modifications to the ECS ducting configuration and circuits are not completed in the planned 18-month window between Artemis I and Artemis II, Then: There is a possibility that the ECS construction will not be completed in time to allow for V&V prior to vehicle processing for Artemis II.	To support launches post Artemis I, modifications are planned to the ECS that will enable it to support both Block 1 and Block 1B vehicles. This will require modifications to the existing circuits; however, these circuits must be maintained throughout the entire Artemis I launch campaign. Mitigation efforts being pursued include compressing the design schedule, improving design package flexibility, identifying design scope that can be deferred, exploring alternate implementation methods, and/or reducing the overall verification and validation schedule.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Risk Statement	Mitigation
If: ML-2 construction experiences design and construction delays, Then: ML-2 readiness for Artemis IV could be delayed.	EGS Program management is working with the prime contractor to shore up the discipline and rigor associated with project execution. NASA leadership has also increased oversight on the ML-2 project to ensure remaining development and construction work is executed as efficiently as possible. The program has seen challenges due to the COVID-19 pandemic, particularly in the areas of market pricing on materials/services and labor inefficiencies.

Acquisition Strategy

EGS serves as its own prime contractor for development activities. EGS executes SLS and Orion ground infrastructure and processing requirements by leveraging Center and programmatic contracts. For more routine work, EGS also uses pre-qualified indefinite-delivery, indefinite-quantity contractors while exercising full and open competition for larger or more specialized projects, such as facility systems construction contracts and associated GSE fabrication firm-fixed-price contracts. A fixed-price contracting approach is the first choice whenever possible, as it provides maximum incentive for contractors to control costs because the contractors are subject to any losses incurred. In addition, a fixed-price contract imposes less administrative burden on the contracting parties.

MAJOR CONTRACTS/AWARDS

EGS development activities will encompass projects of varying content and size. EGS does not have a prime contract; it uses the Center's institutional contracts to execute the development, engineering, construction, and programmatic activities. If the project size or scope falls outside existing Center capabilities, then a competitively bid firm-fixed-price contract will be used.

Element	Vendor	Location (of work performance)
ML-1 Structural and Facility Support Modification Contract	J.P. Donovan Construction, Inc.	KSC
VAB Platform Construction	Hensel Phelps Construction, Inc.	KSC
ML-2 Design Build	Bechtel National, Inc.	KSC

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Preliminary Design Review (PDR)	Standing Review Board (SRB)	Mar 2014	To evaluate completeness and consistency of program preliminary design; to determine readiness to proceed with detailed design phase.	Program cleared to proceed to next phase.	N/A
Critical Design Review (CDR)	SRB	Dec 2015	To demonstrate that program design is mature; support full-scale fabrication, assembly, integration, and test; and meet overall performance requirements within cost and schedule constraints.	Program cleared to proceed to next phase.	N/A
System Integration Review (SIR)	KSC Independent Review Team (IRT)	Jun 2018	To evaluate the readiness of the program, including its projects and supporting infrastructure, to begin system Assembly, Integration, and Test with acceptable risk and within cost and schedule constraints.	Program cleared to proceed to next phase.	N/A
Exploration Systems Development (ESD) Artemis I Independent Schedule Assessment	Schedule assessors from Office of the Chief Financial Officer (OCFO)	Jun 2019	Programmatic assessment and analysis of Artemis I schedules across all ESD programs with an emphasis on program performance and risks.	NASA leadership was briefed on Artemis I launch date options. OCFO staff briefed NASA leadership on Artemis I launch date options.	N/A

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Inspector General (IG)	Mar 2020	To assess the Agency's development of its mobile launchers	Audit of NASA'S Development of its Mobile Launchers (IG-20-13). The IG made four recommendations to NASA on changes needed to ensure success with developing a second mobile launcher.	N/A
Performance	Inspector General (IG)	Mar 2020	To evaluate whether NASA's management has taken appropriate steps in developing and managing the risk of its Ground and Flight Application Software for the Artemis Campaign.	NASA's Development of Ground and Flight Application Software for the Artemis Campaign (IG-20-014). The IG made two recommendations to NASA as it proceeded through the remaining Artemis software development.	N/A
ESD Artemis I Re-baseline	IRT	Apr 2020	Programmatic assessment and analysis of Artemis I schedule and schedule risks of Artemis I launch date and JCL.	Established revised baseline and launch readiness date.	N/A

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Inspector General (IG)	Dec 2020	To address NASA's Aerospace Safety Advisory Panel concerns over the Agency's plans to return-to-the-Moon by 2024.	NASA's Challenges to Safely Return Humans to the Moon by 2024 (IG-21-007) IG identified returning to the Moon as a top management and performance challenge and will continue oversight of NASA's management of the Artemis Campaign and the Agency's human exploration efforts through other audits and reviews.	N/A
Performance	General Accounting Office (GAO)	Dec 2020	To assess the progress the programs are making towards Artemis I with respect to schedule and cost, and the extent to which the programs are positioned to support the planned Artemis flight schedule beyond Artemis I.	GAO made two recommendations to establish baselines ahead of a key design review and improve internal reporting about capability upgrades for human space exploration programs beyond Artemis I. NASA concurred with the recommendations made in this report.	N/A

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
ESD Enterprise Integration Review (EIR)	IRT	Jan 2021	To confirm that flight and ground hardware elements, software, support equipment, facilities and infrastructure are ready to support assembly, integration, test, and mission operations per the planned schedule for Artemis I.	The IRT confirmed the programs are sufficiently mature to proceed for integrated operations.	N/A
ML 2 PDR (Technical)	IRT	Mar 2021	To evaluate completeness and consistency of program preliminary design; to determine readiness to proceed to CDR.	Verify technical readiness for the project to initiate construction.	ML 2 PDR (Programmatic)
Performance	Inspector General (IG)	Apr 2021	To provide an update on the NASA 2020 Artemis Plan.	Artemis Status Update (IG-21-018) - IG will continue to monitor the Agency's efforts towards achieving 2020 Artemis Plan.	N/A

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	General Accounting Office (GAO)	May 2021	To assess NASA's ability to accomplish the March 2019 White House direction to accelerate its plans for a lunar landing by four years to 2024.	Significant Work Remains, Underscoring Challenges to Achieving Moon Landing in 2024 (GAO-21-230) - GAO made four recommendations, including that NASA document the process for determining key programmatic and technical tools for the Artemis missions. NASA concurred with three of the recommendations, but not the fourth, which related to the costs included in a lunar rover's cost estimate.	N/A
Performance	Inspector General	Nov 2021	To assess the Artemis Campaign's schedule and projected costs as well as how the Agency's acquisition and programmatic approaches facilitate landing astronauts on the Moon.	NASA's Management of the Artemis Missions (IG-22-003) - IG will continue to monitor acquisition and programmatic approach for Artemis Missions.	N/A
Mobile Launcher 2 PDR (Programmatic)	IRT	Dec 2021	To evaluate completeness and consistency of program preliminary design; to determine readiness to proceed to CDR.	The IRT confirmed the programs are sufficiently mature to proceed to CDR.	CDR

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	General Accounting Office (GAO)	Mar 2022	To update NASA's progress and challenges in working towards the first three Artemis missions.	Moon Landing Plans Are Advancing but Challenges Remain (GAO-22-105533) - GAO restated its 10 previous recommendations related to improving NASA's management of its Artemis efforts and related programs. NASA generally agreed with these recommendations and plans to take steps to implement them.	N/A
Operational Readiness Review/ Flight Readiness Review (ORR/FRR) for Artemis I	IA/IRT	NET May 2022	To evaluate the readiness of the project to operate the flight system and associated ground system; and support systems for safe and successful launch and flight/mission.	N/A	N/A
Launch Readiness Date/Initial Operations Capability (LRD/IOC) for Artemis I	IA/IRT	NET May 2022	To assess all capabilities of the vehicle to support the readiness to launch.	N/A	N/A
Mobile Launcher 2 CDR	IA/IRT	Mar 2022 (U/R)	To demonstrate that program design is mature; support full-scale fabrication, assembly, integration, and test; and meet overall performance requirements within cost and schedule constraints.	N/A	N/A

ARTEMIS CAMPAIGN DEVELOPMENT

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Gateway	501.5	685.0	**779.2**	754.5	685.4	661.7	758.2
Adv Cislunar and Surface Capabilities	45.0	82.0	**59.6**	57.8	62.9	425.2	555.6
Human Landing System	928.3	1,195.0	**1,485.6**	1,863.8	2,246.1	2,168.2	2,537.9
xEVA and Human Surface Mobility Program	197.3	100.0	**275.9**	297.7	494.9	598.8	599.1
Total Budget	**1,672.1**	**2,062.0**	**2,600.3**	**2,973.8**	**3,489.3**	**3,853.9**	**4,450.7**
Change from FY 2022 Budget Request			**538.3**				
Percent change from FY 2022 Budget Request			**26.1%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The Near Earth Asteroid (NEA) Scout shown above is the first CubeSat delivered and ready for integration into Space Launch System (SLS) for the Artemis I mission.

The overarching goal of the Artemis Campaign Development (ACD) theme is to develop the systems that will be used to land humans on the Moon, explore the lunar surface, and prepare for Mars exploration. ACD comprises three programs previously funded under the retired Exploration Research and Development (ERD) theme: Gateway, Advanced Cislunar and Surface Capabilities (ACSC), and the Human Landing System (HLS). It also includes a newly formed program: Exploration Extravehicular Activity (xEVA) and Human Surface Mobility. ACD's work will create the necessary exploration infrastructure in lunar orbit and on the lunar surface that astronauts will use during Artemis missions. ACD is responsible for developing and testing prototype systems, as well as planning and developing flight missions to lunar orbit and the lunar surface. In addition to expanding our Lunar capabilities, these efforts will also inform and enable future missions to Mars. These program objectives support the National Space Policy of 2020 and the 2021 Space Priorities Framework, as well as the Agency's Strategic Goal 2, which seeks to extend human presence to the Moon and onto Mars for sustainable, long-term exploration, development, and utilization.

The Gateway will be a small way station that will orbit the Moon and support human and robotic missions to the lunar surface. Initial elements of the Gateway outpost will be launched together into orbit around the Moon, where they will provide critical infrastructure to enable fully reusable lunar landers. The Gateway will be capable of supporting early human-rated lander deployments and operations enabling lunar surface capability.

ACD leads the next phase of lunar sustainability with the development activities occurring under ACSC. Future systems will provide habitation and cargo landing capabilities, including the Foundation Surface

Habitat and a Lunar Cargo Lander capable of landing major surface elements, both of which are key elements required for sustainability on the lunar surface. These systems have requirements that overlap with requirements likely to be established for crewed Mars missions, and so they also reduce risk and prove capabilities likely needed for eventual missions to Mars.

Through commercial partnerships, HLS will support the development and deployment of the integrated system that will land the first woman and first person of color on the surface of the Moon. The demonstration of an integrated lander is the first step to enable more permanent human access to the lunar surface. The Budget fully funds the lunar lander that will be used for the first Artemis mission to the lunar surface, and also provides funding to support the development of multiple, distinct lunar landers for future missions.

The xEVA and Human Surface Mobility program is formulating the systems that NASA will use to explore the surface of the Moon. These surface systems, including the Lunar Terrain Vehicle, the Habitable Mobility Platform, and xEVA surface suits, will provide capabilities and result in lessons learned expertise that will support future Mars missions.

ACD activities utilize a variety of agreements and contracts that enable NASA, private industry, academia, and international partners to share in the risks and rewards of Government investments. These shared risks include incentivizing technical performance and building future commercial markets with financial interest in developing capabilities. These programs are also utilizing the unique skills of the NASA workforce to perform risk reduction, develop life support systems, and build the missions that will take humanity back to the Moon and beyond.

The missions pioneered by ACD will enable the first intrepid crews of the new space age to travel safely to and from the surface of the Moon and mature sustainability on the Moon. These missions will enable new scientific discoveries and promote new technologies, research, and systems needed to sustain living in deep space for the benefit of all humankind.

EXPLANATION OF MAJOR CHANGES IN FY 2023

ACD has been established as a new theme, encompassing the Gateway, HLS, and ACSC programs that previously resided under the retired ERD theme.

GATEWAY

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**501.5**	**685.0**	**779.2**	**754.5**	**685.4**	**661.7**	**758.2**
Change from FY 2022 Budget Request			**94.2**				
Percent change from FY 2022 Budget Request			**13.8%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

NASA, along with Maxar Technologies and Busek Co., successfully completed a test of the 6-kilowatt (kW) solar electric propulsion (SEP) subsystem destined for the PPE.

The Gateway will serve as a multi-purpose outpost orbiting the Moon that provides essential support for long-term human missions to the lunar surface. The initial Gateway capability will provide systems to enable crewed missions to cislunar space, including capabilities that enable lunar surface missions.

In addition to serving as a destination for astronaut expeditions and scientific research, the Gateway will serve as a port for deep space transportation (e.g., landers in route to the lunar surface or potentially spacecraft embarking to destinations beyond the Moon [including Mars]). Located tens of thousands of miles from the lunar surface at its farthest point and within a couple of thousand miles of the surface at its closest point, the Gateway will be in a near-rectilinear halo orbit. This orbit will allow NASA and its international and commercial collaborators to have unprecedented lunar surface access, conduct deep space science and technology investigations, and perform sustainable lunar exploration.

The integrated Gateway spacecraft will be developed and deployed incrementally. The initial Gateway architecture is focused on two foundational elements: the Power and Propulsion Element (PPE) and the Habitation and Logistics Outpost (HALO). PPE and HALO are targeted to be integrated and launched together on a SpaceX Falcon Heavy rocket in 2025.

As astronauts prepare for missions to the lunar surface, they will need deliveries of pressurized and unpressurized cargo, science experiments, and supplies (e.g., sample collection materials and other items). The Gateway Deep Space Logistics (DSL) Project manages the Gateway Logistics Services (GLS) contract, which will deliver supplies and hardware in support of Gateway's sustained lunar orbit operations and lunar landing missions.

Gateway international partners will provide important contributions to the lunar outpost, including advanced external robotics, additional habitation, a refueling capability, and possibly other enhancements. Canada awarded a contract to MacDonald, Dettwiler and Associates Inc. (MDA) to build the Canadarm3 for Artemis deep space missions. Japan announced plans to join the United States on the Gateway with contributions of habitation components and logistics resupply. The European Space Agency (ESA) signed an agreement with NASA to contribute habitation and refueling modules and enhanced lunar communications to the Gateway.

EXPLANATION OF MAJOR CHANGES IN FY 2023

The xEVA systems will be managed by the newly established Extravehicular Activity (EVA) and Human Surface Mobility (HSM) program office at Johnson Space Center (JSC).

Deep Space Logistics, which was previously funded under Advance Cislunar and Surface Capabilities, has moved to the Gateway Program.

ACHIEVEMENTS IN FY 2021

Multiple bilateral Memoranda of Understanding (MOU) provide the formal commitments between the U.S. Government and partner agencies/governments to fulfill Gateway partnership and contributions, and three MOUs were finalized in FY 2021.

In October 2020, ESA signed an agreement with NASA to contribute habitation and refueling modules, enhanced lunar communications to the Gateway, and two more Orion service modules. ESA agreed to provide the International Habitation module (I-HAB), which will enhance Gateway capabilities for scientific research, life support systems, and crew living quarters. These capabilities enable longer duration crewed Gateway missions.

In December 2020, Canada signed an agreement to provide advanced external robotics. The Canadian Space Agency (CSA) agreed to provide an external robotics system that includes a next-generation robotic arm, Canadarm3, for Gateway.

In December 2020, Japan finalized an agreement with NASA to provide several capabilities for the Gateway's I-HAB. Japan Aerospace Exploration Agency (JAXA) planned contributions include I-HAB's environmental control and life support system, batteries, thermal control, and imagery components, which will be integrated into the module by ESA prior to launch.

Throughout FY 2021, Gateway made significant technical progress with several design reviews at the program and element levels. PPE's contractor, Maxar, held a Part One Preliminary Design Review (PDR), and HALO completed the element PDR. The International Habitat (I-HAB) team completed a Primary Structures PDR and began the full I-HAB System PDR process. The Gateway Program completed a Delta System Definition Review (SDR) Sync Review and achieved Agency-level approval at their Key Decision Point (KDP)-0 to proceed with the formulation phase of the Program.

In FY 2021, Gateway also finalized two key procurement actions. In February 2021, NASA selected SpaceX to provide launch services for PPE and HALO. Originally, PPE and HALO were planned to be launched on separate launch vehicles and autonomously dock in orbit around the Moon. PPE and HALO will now be launched together as an integrated unit, effectively designated as a Co-Manifested Vehicle (CMV). After integration on Earth, the PPE and HALO are targeted to launch together in 2025 on a Falcon Heavy rocket from Launch Complex 39A at Kennedy Space Center (KSC).

In July 2021, Phase 5, the final phase of the HALO contract with Northrop Grumman to cover module production and delivery, was signed.

GATEWAY

WORK IN PROGRESS IN FY 2022

Throughout the year, the Gateway Program and constituent elements will continue through formulation stages at varying levels of maturity. ESA completed their I-HAB PDR Board in November 2021, and the PPE Maxar PDR Part 2 was completed in December 2021. PPE will next hold a Base Completion Review in early calendar year 2022. The HALO Critical Design Review (CDR) process has also been initiated, with a CDR closeout planned for mid-2022.

A Gateway Program PDR Sync Review is planned for Q3 of FY 2022 in preparation for KDP-I. An Agency Baseline Commitment (ABC) and a Program Commitment Agreement (PCA) will be established at this KDP, which will provide Agency approval to proceed from the formulation to the implementation (development) phase.

The ESA ESPRIT and CSA Canadaarm3 will also hold their System Requirements Reviews (SRRs) in FY 2022.

The DSL team and GLS contractor, SpaceX, will continue special studies during FY 2022 in advance of the first mission Authority to Proceed (ATP).

KEY ACHIEVEMENTS PLANNED FOR FY 2023

In Fiscal Year 2023, the Gateway Program will reach critical design review maturity with a CDR-informed synchronization review and the Gateway Initial Capability (PPE/HALO) will begin the Assembly, Integration, and Test (AI&T) phase. Key additional planned achievements include ship and delivery of the HALO habitable element, manufactured by Thales Alenia Space Italia (TASI), in November 2022. This will initiate the AI&T phase of HALO development. Bus integration for PPE is scheduled for completion in July 2023. The PPE-HALO commercial launch vehicle is planning to hold a mission specific PDR in May 2023.

Program Projects

POWER AND PROPULSION ELEMENT (PPE)

The PPE is a high-power, 50-kilowatt solar electric propulsion spacecraft that will provide power, high-rate communications, attitude control, orbit maintenance, and orbital transfer capabilities for the Gateway.

The PPE project leverages Space Technology Mission Directorate investments in Advanced Electric Propulsion Systems. PPE will demonstrate an advanced SEP system, which combines 12kW and 6kW SEP thrusters. The PPE will be the most powerful electric propulsion spacecraft ever flown and it will maneuver Gateway around the Moon, opening up more of the lunar surface for exploration than ever before.

The PPE is being developed and built by Maxar Technologies of Westminster, Colorado, and is managed out of NASA’s Glenn Research Center in Ohio. Maxar Technologies was awarded the contract for PPE in 2019. PPE will be launched with HALO as an integrated vehicle on a SpaceX Falcon Heavy commercial rocket, and PPE will propel the co-manifested vehicle to cislunar space.

GATEWAY

HABITATION AND LOGISTICS OUTPOST (HALO)

HALO is where astronauts will live and conduct research while visiting the Gateway. The pressurized living quarters will provide command and control systems for the lunar outpost, and docking ports for visiting spacecraft, such as NASA's Orion spacecraft, lunar landers, and logistics resupply craft. The HALO module will serve as the backbone for command and control and power distribution across Gateway and will perform other core functions, including hosting science investigations via internal and external payload accommodations and communicating with lunar surface expeditions. HALO also will enable the addition of the I-HAB habitable element to expand Gateway capabilities. HALO leverages contributions from the Gateway international partners for robust capabilities. Batteries provided by JAXA will power HALO until PPE solar arrays can be deployed and during eclipse periods. Robotic interfaces provided by CSA will host payloads and provide base points for Canadarm3 robotic operations. ESA will provide a lunar communications system to enable high-data-rate communications between the lunar surface and Gateway.

Northrop Grumman was awarded a contract for HALO in June 2020. Northrop Grumman's design for HALO, developed through NASA's NextSTEP contract vehicle, is based on its Cygnus spacecraft currently being used to deliver cargo to the International Space Station. HALO will be launched with PPE as an integrated vehicle on a SpaceX Falcon Heavy commercial rocket.

DEEP SPACE LOGISTICS (DSL)

The functional reality of human habitation in any location on Earth or in space is that it involves the consumption of resources and the generation of waste. The development of a sustainable, repeatable, and reliable supply chain is critical to the success of Deep Space habitation. The DSL Project is the element of the Gateway Program charged with establishing a sustainable Deep Space delivery capability for exploration.

The Logistics spacecraft will have their own power, propulsion, and navigation systems to rendezvous autonomously with the Gateway in cislunar orbit and dock at a radial port. The Logistics spacecraft will provide consumable resupply, outfitting equipment, and cargo delivery including utilization and spares. The Logistics module is designed to serve as a large pantry where supplies can be easily accessed by the crew. The design of the spacecraft will accommodate the collection, storage, and eventual disposal of waste accumulated at Gateway. The cargo and supplies delivered by the Logistics spacecraft will support habitation of the Gateway as well as provide provisions for the lunar landers during the sustained lunar exploration phase.

Logistics flights are necessary to supply Gateway with critical cargo deliveries and maximize the length of crew stays on Gateway. The GLS contract and technical capability are extensible to deliver unique payload configurations and supply cargo deliveries to the lunar surface as well as other Deep Space destinations. As an example, the Canadian robotic arm will be supplied to Gateway via a logistics flight in 2027.

In March 2020, NASA awarded SpaceX as the first U.S. commercial provider under the Gateway Logistics Services contract to deliver cargo and other supplies to the lunar outpost. ATP has not yet been provided for the first mission.

INTERNATIONAL HABITAT (I-HAB)

The I-HAB module is a contribution from ESA and will provide additional crew habitation and workspace, as well as additional environmental systems capability. This module will also provide additional docking ports and accommodations for internal and external science experiments. I-HAB's environmental control and life support systems will augment the life support system capabilities provided by HALO and the docked Orion, enabling longer missions at the Gateway and on the lunar surface. JAXA plans to provide several capabilities for the Gateway's I-HAB, including I-HAB's environmental control and life support system, batteries, thermal control, and imagery components, which will be integrated into the module by ESA prior to launch. ESA is under contract with Thales Alenia Space for the I-HAB module, and delivery of I-Hab to the Gateway will be via the SLS Block 1B launch vehicle with Orion providing orbital insertion and docking.

EUROPEAN SYSTEMS PROVIDING REFUELING, INFRASTRUCTURE, AND TELECOMMUNICATIONS (ESPRIT)

The ESPRIT, or European System Providing Refueling, Infrastructure, and Telecommunications, provides additional capabilities that are realized in two components. The first, the HALO Lunar Communications System (HLCS), will be integrated and launched with HALO and will provide high-rate communications relay between Gateway and elements on the lunar surface. The second, separate module is the ESPRIT Refueling Module, which will provide additional fuel capacity to resupply PPE and crew observation windows. ESA is under contract with Thales Alenia Space for the ESPRIT module. NASA plans to deliver the ESPRIT Refueling Module to the Gateway via the SLS Block 1B launch vehicle with Orion providing orbital insertion and docking.

GATEWAY EXTERNAL ROBOTICS SYSTEMS (GERS)

NASA and CSA reached an agreement for CSA to provide the Gateway's external robotics system, including a next-generation robotic arm, known as Canadarm3. Canadarm3 will move end-over-end to reach many parts of the Gateway's exterior, where its anchoring "hand" will plug into specially designed interfaces. CSA also will provide robotic interfaces for Gateway modules, which will enable payload installation including that of the first two scientific instruments launching on the foundational Gateway elements (PPE/HALO). Canadarm3 will be used to conduct maintenance, to berth and inspect vehicles, install science payloads, and support potential future Gateway EVAs. CSA will be responsible for end-to-end external robotics, including engineering and operations.

MDA was selected by CSA for both the Canadarm3 and external robotic interfaces.

Delivery of Canadarm3 to Gateway is targeted in 2027 via a Gateway Logistics Services mission.

GATEWAY AIRLOCK

The Gateway airlock module will support both crewed spacewalks as well a science airlock to transfer scientific experiments and Gateway hardware between the pressurized cabin and the exterior of Gateway. Canadarm3 will be an integral part of the science airlock operations moving the hardware into and out of the science airlock and deploying/retrieving around Gateway.

NASA will continue to discuss Airlock options with the International Partner community.

Program Schedule

The Gateway Program and constituent elements are in the formulation phase. Additional milestones will be identified after Gateway KDP-I.

Date	Significant Event
Q3 FY 2022	Gateway PDR-informed Sync Review
Q4 FY 2022	Gateway KDP-I

Program Management & Commitments

In 2019, the Human Exploration and Operations Mission Directorate (now Exploration Systems Development and Space Operations Mission Directorates [ESDMD/SOMD]) Associate Administrator (AA) assigned authority for the Gateway Program to JSC. The Program Manager reports to the Deputy Associate Administrator (DAA) for the Artemis Campaign Division (ACD) in coordination with the ESDMD AA. The Gateway program will make an ABC for the initial capability spacecraft following the PDR-informed Sync Review and KDP-I. DSL will make a separate ABC at KDP-C.

Program Element	Provider
PPE	Provider: Maxar Technologies Lead Center: GRC Performing Center(s): GRC and JSC
HALO	Provider: Northrop Grumman Lead Center: JSC Performing Center(s): JSC
DSL	Provider: SpaceX Lead Center: KSC Performing Center(s): KSC

Acquisition Strategy

Gateway's integrated acquisition strategy includes procurements and international partner contributions. NASA conducted an Acquisition Strategy Meeting (ASM) in August 2018 to determine center roles/responsibilities assignments (depicted in the previous table) and the acquisition strategy for each Gateway element. Domestic Gateway elements are procured using fixed-price, milestone-based contracts to the greatest extent possible. All major contracts have been awarded. The sections below identify the major domestic contracts.

PPE was awarded on May 23, 2019 to Maxar Technologies.

Orbital Sciences Corporation, a wholly owned subsidiary of Northrop Grumman Space (NGS), referred to as Northrop Grumman here, was selected as one of the habitation partners under the Next Space Technologies for Exploration Partnerships (NextSTEP) contract vehicle on September 3, 2015. The contract scope was authorized over five phases initially beginning with defining the architecture and concepts. The latest (Phase 5) was for final HALO production and delivery was signed on July 8, 2021.

The first Gateway Logistics Services (GLS) contract was awarded in March 2020 to SpaceX.

NASA selected SpaceX to provide a Falcon Heavy launch vehicle for the co-manifested PPE/HALO launch through a competitive Launch Service Task Order evaluation under the NASA Launch Services II contract.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
PPE (May 2019)	Maxar Technologies	Westminster, CO
HALO (Jun 2020)	Northrop Grumman	Dulles, VA
Gateway Logistics Services (Mar 2020)	SpaceX	Hawthorne, CA
CMV Launch Vehicle Provider (Feb 2021)	SpaceX	Hawthorne, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Gateway Formulation Synchronization Review (FSR)	Independent Review Team	Feb 2019	Equivalent to a System Requirements Review (SRR), the FSR evaluated the program's functional and performance requirements, ensuring proper formulation and correlation with Agency and mission directorate strategic objectives.	Program cleared to proceed to next phase	Gateway SDR-informed Sync Review
Gateway Program SDR-informed Sync Review	Standing Review Board (SRB)	Jun 2020 Delta - Mar 2021	To evaluate the credibility and responsiveness of the proposed program requirements / architecture to the mission directorate requirements and constraints, including available resources, and allocation of requirements to projects. To determine whether the maturity of the program's mission/system definition and associated plans are sufficient to begin preliminary design.	Approval to proceed in Formulation at KDP-0	Gateway PDR-informed Sync Review

GATEWAY

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Gateway Program PDR-Informed Sync Review	SRB	May 2022	To evaluate the completeness/consistency of the program's preliminary design, including its projects, in meeting all requirements with appropriate margins, acceptable risk, and within cost and schedule constraints, and to determine the program's readiness to proceed with the detailed design phase of the program.	TBD at KDP-I	Gateway CDR-informed Sync Review

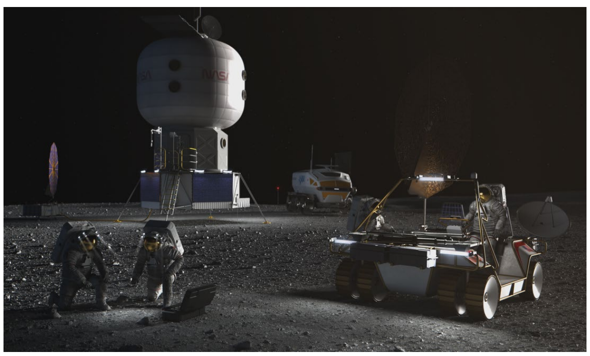
ADV CISLUNAR AND SURFACE CAPABILITIES

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**45.0**	**82.0**	**59.6**	**57.8**	**62.9**	**425.2**	**555.6**
Change from FY 2022 Budget Request			**-22.4**				
Percent change from FY 2022 Budget Request			**-27.3%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



Shown here is an artist rendition of future systems including the Foundation Surface Habitat to enable long duration stays on the lunar surface.

The Advanced Cislunar and Surface Capabilities (ACSC) program manages and integrates the systems that NASA will use throughout the Artemis Campaign to access and explore the surface of the Moon.

ACSC funds the team that leads the integration of the human space flight elements of the Artemis missions starting with Artemis III. This integration team comprises the system engineering, safety, operations, and programmatic organizations that ensure the human spaceflight lunar mission are implemented successfully with contributions from the programs across the Exploration Systems Development Mission Directorate (ESDMD).

Future Systems Formulation (FSF) formulates the systems that NASA will use to sustainably explore the surface of the Moon. These systems, including cargo landing and habitation, will provide capabilities to support future Artemis missions and act as analogs for future Mars missions. FSF will utilize initial studies and pre-formulation activities to initialize element system requirements. As these technologies and systems mature, they will be the building blocks for the capability to extend stays on the Moon.

In the near term, FSF is conducting risk-reduction studies to identify required lunar surface technologies to be utilized on the lunar surface and act as precursor systems for potential future missions. These surface systems include a human class cargo lunar lander and a future surface habitat.

FSF will work with the Moon & Mars Architecture (M&MA) team to oversee the Agency’s habitation strategy and assist the central management authority for Next Space Technologies for Exploration Partnerships (NextSTEP) Broad Area Announcement (BAA), a public-private partnership model seeking commercial development of deep space exploration capabilities to support human spaceflight missions.

In this capacity, FSF and M&MA are the primary interfaces between the external NextSTEP partners and internal stakeholders, including Space Technology Mission Directorate, ISS, Orion, SLS, the Human Research Program, and the Space Communications and Navigation program. Through NextSTEP contracts, NASA and industry identify commercial capability development for low-Earth orbit (LEO) that intersects with the Agency's long-duration, deep space habitation requirements, along with any potential options to leverage commercial LEO advancements and promote commercial activity in LEO. The multiple phases of NextSTEP are informing NASA's conceptual future deep space, long-duration habitation capability.

EXPLANATION OF MAJOR CHANGES IN FY 2023

ACSC will fund the Artemis Campaign Division integration team, previously funded under Exploration Capabilities (EC) program and the newly formed Future Systems Formulation efforts.

System Engineering and Integration activities, including Technical Integration and M&MA, that previously fell under ASCS are now realigned under the newly created Human Exploration Requirements & Architecture Theme.

ACSC will no longer fund Deep Space Logistics which has moved to the Gateway Program.

The Lunar Terrain Vehicle, the surface pressurized rover, and Extravehicular Activities (EVA) will move to the EVA and Mobility program office currently being established at Johnson Space Center (JSC).

ACHIEVEMENTS IN FY 2021

ACSC continued to support the Solar Systems Trek software application, which combines images and other science data to simulate exploration of the solar system, including the Moon, Mars, and small-bodies (e.g., asteroids). This application can be used to inform future missions including the return to the lunar surface through the Human Lander System.

The M&MA activity initiated studies to provide context for how near-term lunar activities can be "Mars forward." M&MA identified potential lunar surface systems, operations, and technology which, through the NextSTEP BAA, will help NASA and industry identify commercial capability development for LEO that intersects with the Agency's long-duration, deep space habitation requirements, along with any potential options to leverage commercial LEO advancements and promote commercial activity in LEO. The multiple phases of NextSTEP are informing NASA's conceptual future deep space, long-duration habitation capability. M&MA will be funded by Human Exploration Requirements & Architecture (HERA) in FY 2023.

WORK IN PROGRESS IN FY 2022

Through a partnership with the Korea Aerospace Research Institute (KARI), ACSC will deliver the ShadowCam flight instrument for launch on the Korea Pathfinder Lunar Orbiter (KPLO) in 2022. NASA will provide Deep Space Network lunar navigation and trajectory assistance in return for accommodating ShadowCam, an instrument developed by Arizona State University in collaboration with NASA, which will image the shadowed regions at the Moon's poles to detect the presence of ice and potentially help to identify future sites for human lunar landings and surface operations.

The M&MA team will conduct risk-reduction activities to identify risks, capability gaps, and requirements to ensure mission success for ACD. This activity will transfer to the Human Exploration Requirements & Architecture Theme in FY 2023.

ADV CISLUNAR AND SURFACE CAPABILITIES

KEY ACHIEVEMENTS PLANNED FOR FY 2023

ACSC will advance technologies to prevent the accumulation of lunar dust on surface systems and protect the crew from the hazardous effects of dust upon the return of humans to the lunar surface and subsequent long duration missions.

Future Systems Formulation will continue conducting risk-reduction activities to further develop key elements of the Artemis plan for the lunar surface. FSF will execute the strategic direction from ESDMD regarding commercial and international collaborations to begin development of systems based on the surface pressurized rovers, surface habitats, and transit concepts.

The integration team under ACSC will continue to manage the integration and required synergies across the Artemis Campaign Division, working closely with the HLS, Gateway, EVA and Human Mobility, and Future Systems Formulation to ensure that the Artemis Missions are successfully executed while driving human exploration of the Moon toward sustainability.

Program Elements

ACD PROGRAM INTEGRATION

Artemis Campaign Development (ACD) division is responsible and accountable for the Programmatic integration of the Gateway, Human Lander Systems, ACSC and Exploration Capabilities Programs. ACD leverages the ESDMD Resource Management Office (RMO) and is infused with embeds from other NASA Headquarters (HQ) offices, as well as cross-directorate teams with Common Exploration Systems Development (CESD).

ACD manages the definition, certification, and operation of the systems that establish a sustained human presence in cislunar space as well as architecture and technical baseline. ACD also maintains content in the products that define the baseline at the ESDMD level. ACD supports configuration and data management for AES activities, directs cross-program integration activities that involve ACD objectives, and manages the various technical risks that affect sustaining operations.

ACD works closely with the Space Operations Mission Directorate and ESDMD program Systems Engineering and Integration organizations to ensure that technical efforts are effective and integrated.

FUTURE SYSTEMS FORMULATION

The future systems group conducts activities that will lead directly to the development of capabilities based on the surface habitat and lunar cargo lander concepts, as well as other systems required for NASA to continue to advance human exploration.

Program Schedule

Currently all systems are in pre-formulation and schedules have not been defined.

Program Management & Commitments

ESDMD manages the ACSC activities.

Program Element	Provider
ACD Integration	Provider: NASA Centers Lead Center: NASA Headquarters (HQ) Performing Center(s): Marshall Space Flight Center (MSFC), Langley Research Center (LaRC), Glenn Research Center (GRC), Goddard Space Flight Center (GSFC), Johnson Space Center (JSC), Jet Propulsion Laboratory (JPL), Kennedy Space Center (KSC), Ames Research Center (ARC), Armstrong Flight Research Center (AFRC) Cost Share Partner(s): N/A
Future Systems	Provider: TBD Lead Center: HQ Performing Center(s): MSFC, JSC, JPL, KSC, ARC Cost Share Partner(s): TBD

Acquisition Strategy

No acquisition planned for this program.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

None.

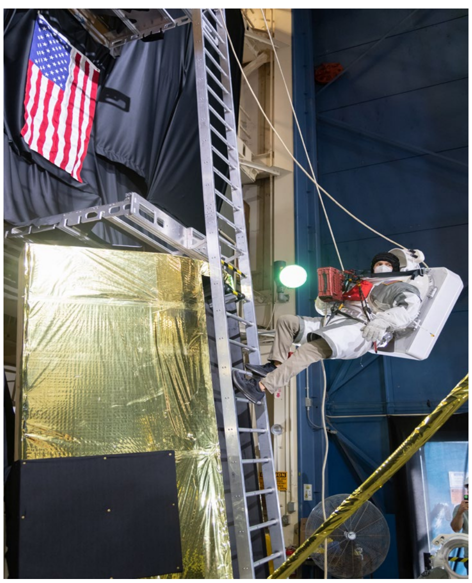
HUMAN LANDING SYSTEM

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**928.3**	**1,195.0**	**1,485.6**	**1,863.8**	**2,246.1**	**2,168.2**	**2,537.9**
Change from FY 2022 Budget Request			**290.6**				
Percent change from FY 2022 Budget Request			**24.3%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



During the HLS Appendix H Base Period, NASA worked with each contractor on a variety of task agreements to further requirements and inform architecture for the Option A HLS including ingress/egress testing for the Lunar Surface (shown here).

The Human Landing System (HLS) program is an integral part of achieving NASA's Artemis goals through landing United States astronauts, including the first woman and first person of color, on the Moon as part of a sustained exploration program.

Utilizing partnerships and competition to ensure affordability, the program will leverage commercial capabilities to the maximum extent possible for the development of an integrated landing system. Through the award of the initial landing demonstration to SpaceX, as well as the Appendix N awards for Sustainable HLS Studies and Risk Reduction, NASA is working with multiple industry partners to support development of integrated landing systems that can transport crew to and from the lunar surface and maintain competition in the HLS program. The lunar landing demonstration will consist of two crew members who will travel to lunar orbit in the Orion spacecraft and board the HLS for the final leg of their journey to the surface of the Moon. After approximately a week exploring the surface, the crew will board the HLS for their trip back to lunar orbit, where they will return to Orion before heading back to Earth.

NASA teams will work closely with United States industry to provide insight and expertise to ensure it meets NASA's performance requirements and human spaceflight standards. These agreed-upon standards, which range from the technical areas of engineering, safety, health, and medical, are a key tenet of safe systems.

In addition, NASA intends to contract for sustainable transportation services to and from the lunar surface for long-term exploration of the Moon, staged from the Gateway. The Agency has announced plans regarding NASA's need for Sustaining Lunar Transport to achieve service missions for the late 2020s and is reaching out to all potential industry providers for input. NASA intends to support the development and use of multiple landing systems to maintain competition in the HLS program.

HUMAN LANDING SYSTEM

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

ACHIEVEMENTS IN FY 2021

NASA selected three United States companies to design and develop HLS for the Agency's Artemis Campaign. The human landing system awards under the Next Space Technologies for Exploration Partnerships (NextSTEP-2) Appendix H Broad Agency Announcement (BAA) were firm-fixed price, milestone-based contracts. The total combined value awarded for the contracts was $856 million for the base period.

The following companies were selected to design human landing systems during the base period which ended in spring 2021:

Blue Origin of Kent, Washington, is developing the Integrated Lander Vehicle (ILV) – a three-stage lander to be launched on its own New Glenn Rocket System and the United Launch Alliance's (ULA) Vulcan launch system.

Dynetics (a Leidos company) of Huntsville, Alabama, is developing the Dynetics Human Landing System (DHLS) – a single structure providing the ascent and descent capabilities that will launch on the ULA Vulcan launch system.

SpaceX of Hawthorne, California, is developing the Starship – a fully integrated lander that will use the SpaceX Super Heavy rocket.

These companies offered three distinct lander and mission designs, offering dissimilar redundancy, driving a broad range of technology development, and, ultimately, more sustainability for lunar surface access.

On April 16, 2021, NASA announced the selection of SpaceX to deliver the next American astronauts from lunar orbit to the surface of the Moon aboard the company's Starship Human Landing System. After the selection of SpaceX to move on as the provider of the initial phase of HLS, protests were filed with the U.S. Government Accountability Office (GAO) concerning the HLS selection. The protest was resolved, allowing SpaceX to proceed as the HLS selection for NASA. However, the protests and a subsequent lawsuit filed against NASA in the U.S. Court of Federal Claims, all of which upheld NASA's HLS procurement actions, did result in a multi-month delay to the HLS program and the Artemis Campaign.

NASA announced plans for and awarded five Appendix N firm fixed-price milestone-based contracts for the NextSTEP-2 BAA Appendix N, which will fund continued development of other landing systems in the runup to the competition for the lunar crewed transportation services procurement. The work, focusing on refining requirements, concepts, and technical specifications, will be conducted over the next 12 months with the awardees: Blue Origin, Dynetics, Lockheed Martin, Northrup Grumman, and SpaceX.

WORK IN PROGRESS IN FY 2022

With the resolution of the GAO and legal processes, NASA worked with SpaceX to update and release a revised schedule for the milestones leading up to the HLS Artemis missions.

HUMAN LANDING SYSTEM

NASA is currently engaged in numerous product development and review activities to support the Sustaining Lunar Development Request For Proposal (RFP) in FY 2022 to U.S. industry for sustaining lunar landing development and demonstrations. This is being informed by industry responses to a NASA Request for Information (RFI) and through the work on Appendix N. NASA is working to have a draft RFP available for review in Spring of 2022, with a formal RFP to follow.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

HLS, with industry, will continue to design and develop lander systems for the initial return of American astronauts to the lunar surface.

The Sustaining Lunar Development RFP will be followed by a review and proposal evaluation period leading to proposal selection and award currently targeted for January 2023.

Program Elements

HLS PROGRAM MANAGEMENT

Human Landing System Program Management is responsible for executing programmatic roles assigned to Marshall Space Flight Center (MSFC) by the Exploration Systems Development Mission Directorate (ESDMD). The HLS Program Office will oversee all HLS verification, validation, and certification to ensure requirements for flight readiness satisfy NASA’s standards for crew safety and human rating.

HLS Program Management is responsible for the insight and oversight activities in collaboration with commercial partners associated with human landing system hardware development, integration, and flight demonstration, leading to services that can be procured by NASA. HLS performs risk reduction activities and identifies and prioritizes upgrades to the human landing systems so it can support sustainable future exploration missions. HLS will include a lander ground operations office at Kennedy Space Center (KSC), and both a crew compartment office and a lander flight operations office at Johnson Space Center (JSC). HLS will also prioritize and coordinate collaboration resources across multiple NASA centers and manage major integrated system test activities, as applicable.

HUMAN LANDING SYSTEMS

HLS will support development of the landing system that will carry astronauts to and from the lunar surface. The SpaceX design will complete an uncrewed landing demonstration followed by a crewed landing demonstration that includes astronaut exploration of the surface.

HLS continues working with multiple American companies to bolster competition and commercial readiness for the procurement of sustainable transportation services to and from the lunar surface for the long-term exploration of the Moon staged at the Gateway.

SUSTAINABLE STUDIES AND RISK REDUCTION

Contracts established under NextSTEP-2 Appendix N BAA (Sustainable Human Landing System Studies and Risk Reduction) provide for engagement with potential commercial partners for architecture concept development and risk reduction activities.

HUMAN LANDING SYSTEM

Program Schedule

Date	Significant Event
Mar 2020	Selected and awarded multiple industry partners for base contract period
Apr 2021	Selected SpaceX for initial HLS demonstration mission
2024	Uncrewed HLS demonstration
NET 2025	Crewed HLS demonstration
NET 2027	First mission utilizing sustainable transportation services to and from the lunar surface

Program Management & Commitments

Program Element	Provider
HLS Program Management	Lead Center: MSFC Performing Center(s): Ames Research Center (ARC), Glenn Research Center (GRC), Langley Research Center (LaRC), Goddard Space Flight Center (GSFC), Stennis Space Center (SSC), JSC, KSC Cost Share Partner(s): TBD
Integrated Lander	Provider: TBD Lead Center: MSFC Performing Center(s): TBD Cost Share Partner(s): TBD

Acquisition Strategy

The HLS program utilizes the NextSTEP BAA contract vehicle. Through this approach, NASA awards firm-fixed-price, milestone-based proposals to enable rapid development of a crewed flight demonstration of the HLS. NASA has structured the solicitation to award contracts with the following contract line item numbers (CLINs):

- Base CLIN - contract award through 10 months - only long-lead items supporting the first mission and various design activities are allowed during this base period.
- Option A CLIN - flight and landing demonstrations of human landing systems.

The HLS program is currently evaluating acquisition vehicles for sustainable transportation services to and from the lunar surface for long-term exploration of the Moon, staged from the Gateway. The Agency has announced the intent to support Sustaining Lunar Development leading to Sustaining Lunar Transport services.

HUMAN LANDING SYSTEM

MAJOR CONTRACTS/AWARDS

Next Space Technologies for Exploration Partnerships (NextSTEP-2) Appendix H Broad Agency Announcement (BAA) Option A: Selected SpaceX of Hawthorne, California. SpaceX is developing the Starship – a fully integrated lander that will use the SpaceX Super Heavy rocket.

NASA has selected five U.S. companies to help the Agency enable a steady pace of crewed trips to the lunar surface under the Agency's Artemis Campaign. These companies will make advancements toward sustainable human landing system concepts, conduct risk-reduction activities, and provide feedback on NASA's requirements to cultivate industry capabilities for crewed lunar landing missions.

The awards under the Next Space Technologies for Exploration Partnerships (NextSTEP-2) Appendix N broad Agency announcement are firm fixed-price, milestone-based contracts.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Human Landing Systems Program	Standing Review Board (SRB)	Spring 2022	To evaluate the completeness/ consistency of the planning, technical, cost, and schedule baselines developed during formulation; assess compliance of the preliminary design with applicable requirements; and determine if the project is sufficiently mature for HLS Program Key Decision Point (KDP)-C	TBD	KDP-C

Historical Performance

The human landing system awards under the Next Space Technologies for Exploration Partnerships (NextSTEP-2) Appendix H Broad Agency Announcement (BAA) advanced the HLS designs to maturity. The Appendix H: Base Period was completed on schedule in April 2021 and incurred no additional costs outside of the firm fixed priced contractual agreements.

xEVA AND HUMAN SURFACE MOBILITY PROGRAM

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**197.3**	**100.0**	**275.9**	**297.7**	**494.9**	**598.8**	**599.1**
Change from FY 2022 Budget Request			**175.9**				
Percent change from FY 2022 Budget Request			**175.9%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Shown here, the xEVA team conducts the Lunar Surface Gravity and Lighting Conditions concept evaluation at the Neutral Buoyancy Laboratory at Johnson Space Center (JSC).

The Exploration Extravehicular Activity (xEVA) and Human Surface Mobility (HSM) program develops and manages the systems that NASA will use to explore the surface of the Moon. These surface systems, including surface suit and mobility systems, will provide capabilities and result in lessons learned for expertise that will support future Mars missions. The xEVA and Human Surface Mobility program will execute acquisition plans for future surface systems and elements required for lunar sustainability. As these lunar-related technologies and systems mature, they will be the building blocks for the capability to enable more productive stays on the Moon.

The Lunar Terrain Vehicle (LTV) is an unpressurized surface transportation system concept that would significantly extend the range of crew excursions and enable more scientific research, resource prospecting, and exploration activities to be conducted. The LTV could also be teleoperated to perform scientific activities during the non-crewed lunar periods and transport small deployable assets to desirable locations.

Artemis astronauts exploring the lunar South Pole will wear new spacesuits that stand up to the Moon’s harsh environment and keep them safe. NASA is embracing commercial collaborations to optimize spacesuit technology and inspire pioneering in the space market. The Exploration Extravehicular Activity (xEVA) System, which is required for astronauts to conduct moonwalks on the lunar surface, includes the Exploration Extravehicular Mobility Unit (xEMU) spacesuit development, vehicle interfaces to suit equipment (VISE), system servicing equipment, and specialized tools for these moonwalks. The xEMU is designed to provide astronauts with enhanced mobility to accomplish their exploration tasks on the lunar surface. It is also designed to be more comfortable when worn by male and female astronauts with a wider range of physiological characteristics.

Long duration mobility is a key enabler of more productive lunar exploration. The surface pressurized rover (SPR) is a pressurized surface transportation system concept that would be used on the Moon to expand the range of excursions even further, allowing crews to perform longer-duration research and exploration activities. In addition, this capability would allow NASA to conduct analogs of Mars surface activities to reduce risk and optimize operational concepts.

EXPLANATION OF MAJOR CHANGES IN FY 2023

The Exploration Extravehicular Activity (xEVA) and Human Surface Mobility (HSM) program office has been established at Johnson Space Center (JSC). Funding for the xEVA project will remain as requested in the FY 2022 President's Budget through the end of that fiscal year, with funding under the Space Operations account under the ISS Program, and the Exploration account under the Advanced Cislunar and Space Capabilities program. In FY 2023 and beyond, xEVA funding will be consolidated under this program.

ACHIEVEMENTS IN FY 2021

The xEVA Project released a request for proposals (RFP) for the Exploration EVA Services Contract to procure an "EVA as a Service" solution to provide NASA EVA capability for the International Space Station (ISS), Artemis and advanced program missions. Proposals were received in December 2021. Additionally, the xEVA Project completed the assembly of the two primary xEMU subsystems, the portable life support subsystem (PLSS) and pressure garment subsystem (PGS), and initiated subsystem-level design verification on both subsystems. xEVA also completed the first three of six series of simulated on-orbit EVAs for the Suit Water Membrane Evaporation Flight Experiment (SERFE) and entered the planned on-orbit dwell with the hardware operating nominally.

In August 2021, the LTV activity engaged industry through a request for information. Through the request for information, NASA gained input on challenges associated with the LTV's lifetime, including surviving the long, cold lunar night, and options to transport the vehicle to the lunar surface. Responses to the RFI were received in early 2022. Additionally, LTV began early physical evaluation of crew relevant task to evaluate potential design solution for common crew tasks, seating, crew restraint, and control interfaces.

WORK IN PROGRESS IN FY 2022

In FY 2022, xEVA Project will award the Exploration EVA Services (xEVAS) contract to provide spacesuit and spacewalking services to support both ISS and Artemis missions and will complete design verification testing (DVT) of the integrated xEMU design verification test unit. Additionally, the xEVA Project will complete on-orbit testing of the SERFE, following a planned six-month dwell period to simulate planned quiescent periods between use. The results from DVT and the SERFE evaluations will be compiled along with all other Government design and test data to support a NASA-led technical review of the Government reference design with the selected xEVAS provider(s).

Extravehicular Activity (EVA) and Mobility will conduct risk-reduction activities and evaluate potential commercial and international collaborations to take the next step in developing the systems and technologies identified in the M&MA activity. Through surface systems, NASA will seek to identify specific system architecture and begin formulation activities on key elements of NASA's Artemis plan. The Lunar Terrain Vehicle, the surface pressurized rover, and EVA will move to the EVA and Mobility program office in FY 2023.

xEVA AND HUMAN SURFACE MOBILITY PROGRAM

NASA will support Japanese Aerospace Exploration Agency (JAXA)-NASA feasibility studies to further refine and coordinate on requirements development, concept of operations development, and review of the JAXA concept for [what]. Activities to support crafting an official agreement will also be supported by the SPR team. The other primary focus will be on risk reduction activities to further refine the suitport concept, which is an augmentation to a traditional airlock, and develop the standard interface and documentation.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

The LTV activity will conduct risk-reduction activities and evaluate potential collaborations to take the next step in developing the systems and technologies required. LTV will award a contract(s) to commercial providers based on a Government purchase option in which the vendor delivers the LTV to the lunar surface in the late 2020s and NASA takes ownership after lunar deployment, system checkout, and initial remote operations on the lunar surface.

SPR will finalize requirements and procurements to begin development of the system that will be delivered to the lunar surface in the late 2020s.

Program Elements

xEVA

The Goal of EVA is to provide a safe, reliable, and effective EVA capability that allows astronauts to survive and work outside the confines of the base spacecraft, in support of both the International Space Station and Artemis.

HUMAN SURFACE MOBILITY

The Human Mobility project will provide the means for astronauts to explore the surface of the Moon in wide ranges beyond any previous capability. The Lunar Terrain Vehicle (unpressurized) and the surface pressurized rover will achieve this goal. Specifically, the habitable volume built into the surface pressurized rover will allow for long range reconnaissance missions.

Program Schedule

The specific schedule is still in the formulation phase and needs to be informed primarily by commercial responses to planned industry engagements. During FY 2022, NASA will make significant progress on establishing milestones, program implementation assignments, and acquisition strategy beyond the initial engagements.

xEVA AND HUMAN SURFACE MOBILITY PROGRAM

Program Management & Commitments

ESDMD manages the xEVA and Human Surface Mobility Systems activities.

Program Element	Provider
xEVA	Provider: TBD Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): TBD
LTV	Provider: TBD Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): TBD
Surface Pressurized Rover	Provider: TBD Lead Center: JSC Performing Center(s): TBD Cost Share Partner(s): TBD

Acquisition Strategy

Acquisition plans for all functions/elements of xEVA and Human Surface Mobility will be varied and depend upon specific activities as this effort is comprised of risk-reduction activities, studies, and pre-formulation work.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

The program will undergo quarterly Directorate Program Management Council reviews, and periodically, representatives from the Office of Chief Engineer, the Office of Safety and Mission Assurance, and the Office of Chief Financial Officer will assess performance during Agency-level Baseline Performance Reviews (BPR). In addition, xEVA and Human Surface Mobility provides briefing reports to, and seeks feedback on planning and development activities from the NASA Advisory Council Human Exploration and Operation Committee and the Technology Committee.

Historical Performance

None.

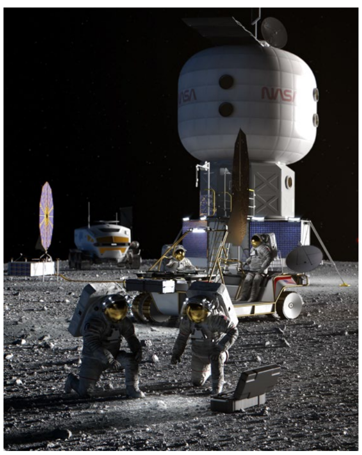
HUMAN EXP REQUIREMENTS & ARCHITECTURE

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Moon & Mars Architecture	9.5	9.5	**48.3**	48.9	49.5	50.0	50.5
Total Budget	**9.5**	**9.5**	**48.3**	**48.9**	**49.5**	**50.0**	**50.5**
Change from FY 2022 Budget Request			**38.8**				
Percent change from FY 2022 Budget Request			**408.4%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



Shown here is an artist's rendition of the United States' return to the lunar surface utilizing systems that will act as precursors to an eventual mission to Mars.

The overarching goal of Human Exploration Requirements & Architecture (HERA) theme is to support the development of human exploration campaigns to the Moon and beyond by identifying the exploration infrastructure required for Artemis missions that will inform future missions to Mars. It also works to ensure that lunar exploration systems are extensible to Mars exploration where technically feasible and cost-effective to do so. These program objectives support the National Space Policy of 2020, the Space Priorities Framework of 2021, as well as the Agency's Strategic Goal 2, which seeks to extend human presence to the Moon and onto Mars for sustainable long-term exploration, development, and utilization.

HERA maintains the Systems Engineering and Integration (SE&I) expertise required to support the top-level technical integration across Exploration Systems Development Mission Directorate (ESDMD), Space Operations Mission Directorate (SOMD), Science Mission Directorate (SMD), and Space Technology Mission Directorate (STMD) to include the Artemis missions and future exploration planning.

HERA also manages the architecture strategy activity that supports mission manifest planning and overall architecture requirements and capability identification.

EXPLANATION OF MAJOR CHANGES IN FY 2023

HERA is a new theme developed in FY 2023. The Exploration Research and Development theme has been retired.

MOON & MARS ARCHITECTURE

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**9.5**	**9.5**	**48.3**	**48.9**	**49.5**	**50.0**	**50.5**
Change from FY 2022 Budget Request			**38.8**				
Percent change from FY 2022 Budget Request			**408.4%**				

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Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The Moon and Mars Architecture program will collaborate with activities across NASA to integrate strategy and architecture for the future of human exploration.

The Moon & Mars Architecture (M&MA) Program is responsible for the integration of strategy and architecture across the Exploration Systems Development Mission Directorate (ESDMD) and the Space Operations Mission Directorate portfolios (SOMD).

In the near term, M&MA is conducting trade studies to reduce risk and identify required technologies to be utilized as part of the Artemis Development Campaign (ACD) and act as precursor systems for potential future Mars Campaign Development (MCD) missions.

M&MA oversees the Agency's strategy in terms of three key components of human space exploration, habitats, mobility, and landing. The habitat group serves as the central management authority for the Next Space Technologies for Exploration Partnership (NextSTEP) contract mechanism, a public-private partnership model seeking commercial development of deep space exploration capabilities to support human spaceflight missions. In this capacity, M&MA has served as the primary interface between the external NextSTEP partners and internal stakeholders, including the Space Technology Mission Directorate, International Space Station, Orion, Space Launch System, the Human Research Program, and the Space Communications and Navigation program. Through the NextSTEP effort, NASA and industry identify commercial capability development for low-Earth orbit (LEO) that intersects with the Agency's long-duration, deep space habitation requirements, along with any potential options to leverage commercial LEO advancements and promote commercial activity in LEO. The multiple phases of NextSTEP are informing NASA's notional future deep space, long-duration habitation capability.

M&MA also maintains the technical integration required to support ESMD and SOMD to include the Artemis missions and future exploration planning. Technical integration includes the following activities:

- Capability Integration for planning and gap analyses of capabilities required for future exploration missions;
- Science and Technology Utilization for coordination and planning for future exploration missions; and

MOON & MARS ARCHITECTURE

- Technical Integration across ESDMD and SOMD programs to support requirements development and configuration control of ESDMD and SOMD level Systems Engineering and Integration documentation.

EXPLANATION OF MAJOR CHANGES IN FY 2023

M&MA is a new Program that will be formally established in FY 2023. ESDMD and SOMD-wide Technical Integration and Architecture Strategy activities focus on the larger Artemis mission plan, emphasizing capability integration strategies and science/technology utilization across the mission directorate. These activities have been transferred from the Advanced Cislunar and Surface Capabilities Program.

ACHIEVEMENTS IN FY 2021

None. Moon and Mars Architecture is a new Program in FY 2023.

WORK IN PROGRESS IN FY 2022

None. Moon and Mars Architecture is a new Program in FY 2023.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

M&MA will conduct risk-reduction activities to identify risks, capability gaps, and requirements to ensure mission success for ACD and MCD.

Program Elements

TECHNICAL INTEGRATION

The Deputy Associate Administrator for Technical Integration and supporting staff are responsible for ensuring the overall ESDMD and SOMD strategies are reflected in program requirements. The office also leads architecture, formulation activities for future exploration mission planning, and provides technical direction for ESDMD and SOMD activities (Moon, Mars, and low-Earth orbit).

ARCHITECTURE STRATEGY

Architecture Strategy activities are focused on developing the future exploration architecture to take humans from the initial Artemis lunar landing to a Mars landing. This architecture will identify needed capabilities and technologies, as well as define operational concepts that will guide the development of flight systems.

Concepts for crewed lunar surface systems such as habitats, rovers, and a robotic precursor to support human exploration will be defined through these studies before being further pursued under Surface Systems.

MOON & MARS ARCHITECTURE

Program Schedule

None.

Program Management & Commitments

ESMD and SOMD manage the M&MA activities.

Acquisition Strategy

None.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

None.

Historical Performance

None.

MARS CAMPAIGN DEVELOPMENT

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**176.2**	**195.0**	**161.3**	**161.6**	**162.7**	**162.7**	**162.8**
Change from FY 2022 Budget Request			**-33.7**				
Percent change from FY 2022 Budget Request			**-17.3%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

FY 2021 and FY 2022 amounts reflect funding previously budgeted for Advanced Exploration Systems under the retired Exploration Research & Development theme.

Perseverance rover, shown here, landed on Mars in February 2021, carrying three MCD-developed instruments. MOXIE demonstrated the first production of oxygen from the atmosphere of Mars in April 2021.

The overarching goal of the Mars Campaign Development (MCD) is to start working on long-lead technology challenges that will need to be solved in order for an eventual crewed mission to Mars to succeed. MCD will address these challenges through a combination of unique in-house activities, industry collaborations, and international partnerships.

MCD is developing and testing prototype technologies, as well as contributing to the planning and development of flight missions to lunar orbit and the Moon to develop systems and operations capabilities that enable an eventual mission to Mars. These program objectives support the National Space Policy of 2020, the Space Priorities Framework of 2021, as well as the Agency's Strategic Goal 2, which seeks to extend human presence to the Moon and onto Mars for sustainable, long-term exploration and utilization.

The Exploration Capabilities program develops habitation systems technologies to enable long-duration missions on the lunar surface and in deep space. The performance and reliability of prototype systems are demonstrated in ISS flight experiments and integrated ground tests. The Exploration Capabilities program also coordinates with the Space Technology Mission Directorate to fill high priority technology gaps that are identified by the ECLSS System Capabilities and Leadership Team (SCLT) and ESDMD’s Systems Engineering and Integration (SE&I) team.

Exploration Capabilities will infuse new technologies into the formulation of future flight programs such as surface habitats and the vehicles that will eventually transport astronauts to Mars.

MARS CAMPAIGN DEVELOPMENT

MCD will begin conducting preliminary concept studies for future systems, namely an eventual transit habitat, that will be needed to provide living quarters and other basic life support functions for an eventual human mission to Mars.

EXPLANATION OF MAJOR CHANGES IN FY 2023

MCD is a new theme developed in FY 2023. Exploration Capabilities will be moved from the retired Exploration Research and Development theme to the Mars Campaign Development theme.

EXPLORATION CAPABILITIES

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**176.2**	**195.0**	**161.3**	**161.6**	**162.7**	**162.7**	**162.8**
Change from FY 2022 Budget Request			**-33.7**				
Percent change from FY 2022 Budget Request			**-17.3%**				

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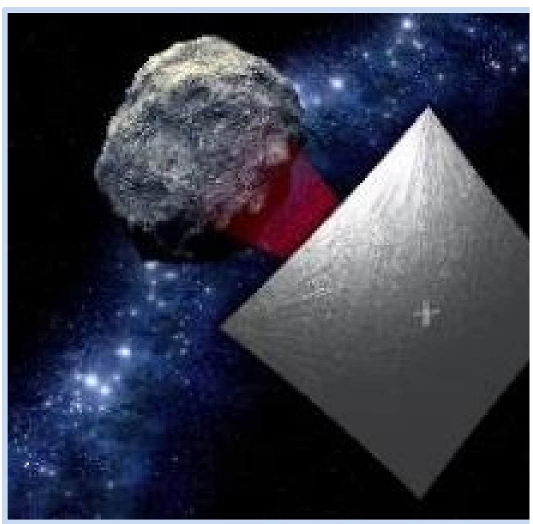
FY 2021 and FY 2022 amounts reflect funding previously budgeted for Advanced Exploration Systems under the retired Exploration Research & Development theme.



Exploration Capabilities will launch 4 cubesat missions in 2022. NEA Scout, pictured above, will fly by a near earth asteroid demonstrating solar sail propulsion, a technology that will be leveraged in future science exploration missions.

Exploration Capabilities (EC) develops high-priority technologies and capabilities, which will be infused into prototype systems that will form the basis for future human spaceflight missions. These activities use a combination of in-house activities and industry collaborations.

To enable NASA's Artemis missions, EC invests in development and demonstration of exploration capabilities to reduce risk, lower life cycle cost, and validate operational concepts for future human missions through habitation capabilities, life support systems, and other technologies. The Agency identifies and addresses potential risks by performing early validation and ground/flight testing of new capabilities prior to integration into planned operational systems. This approach minimizes cost growth and improves affordability of future space exploration. EC focuses on advancing the technologies that will foster a sustainable presence on the Moon and enable a lasting and productive presence utilizing reusable systems. These technologies will provide access for a diverse community of contributing collaborators and sustainability for repeatable trips to multiple destinations across the lunar surface.

To test the technologies, capabilities, and systems required for deep space missions, EC is employing a phased approach by testing on the ground, in low-Earth orbit (LEO), and in cislunar space. The goal is to make exploration missions more capable, safer, and more affordable.

EXPLORATION CAPABILITIES

EC will continue to coordinate with the Space Technology Mission Directorate on identifying and addressing knowledge gaps and delivering fundamental capabilities to provide astronauts with a place to live and work with integrated life support systems, radiation protection, food, fire-safety, avionics and software, logistics management, and systems to manage waste.

EC provides technologies to enable Artemis missions, including capabilities that enable sustained surface missions. The technology capabilities and processes pioneered by EC will enable the crews of the new space age to stay safe and healthy, make scientific discoveries, and sustain new homes away from Earth for the benefit of all humankind.

EXPLANATION OF MAJOR CHANGES IN FY 2023

Exploration Capabilities will be moved from the retired Exploration Research and Development theme to the Mars Campaign Development theme.

The Artemis Campaign Development Integration budget will no longer be under EC and will be funded by Advanced Cislunar and Surface Capabilities (ACSC).

ACHIEVEMENTS IN FY 2021

In support of NASA's goal of extending human space exploration beyond LEO, the division continued development of reliable life support systems, deep space habitats, and overall capabilities reducing logistics requirements necessary to support sustainable human spaceflight missions and eliminating dependencies on frequent resupply from Earth.

Major accomplishments include the launch of the Universal Waste Management System (UWMS) to demonstrate a compact toilet and the Urine Transfer System that will further automate waste management and storage, saving crew member time. The smaller footprint of the UWMS supports possible expansion of the number of crew members on the International Space Station (ISS) and planning for future exploration missions. The team is currently troubleshooting issues with the conductivity sensor that is used to measure the concentration of urine stabilizing liquids. In April 2021, a second UWMS toilet was installed in the Artemis II Orion spacecraft. This new design provides increased crew comfort, less required maintenance time, is 65 percent smaller and 40 percent lighter, and is compatible with multiple vehicles and water recovery systems.

In February 2021, EC delivered the Brine Processor Assembly (BPA) to ISS on NG-15. BPA operations have begun, including its first dewatering cycle on the ISS that will demonstrate significant steps toward increasing overall water recovery to 98 percent, the level desired for Artemis missions.

Two new carbon dioxide scrubbers were delivered to ISS for reliability testing. The Four-Bed CO2 Scrubber and the Thermal Amine Scrubber are being operated simultaneously with 10 crew members onboard. Both systems will run for at least three years to demonstrate reliability. The scrubber with the best performance and reliability will be down selected for infusion into flight systems.

Production work continued with all other life support, logistics reduction, environmental monitoring, and crew health improvements toward ISS flight demonstrations in 2021 and beyond. On September 14-16,

EXPLORATION CAPABILITIES

ECLSS and Crew Health and Performance (CHP) System Capability Leadership Team (SCLT) held its annual meeting. This group is responsible for monitoring and coordinating technology development of key habitation systems and capabilities to reduce launch mass and technology risks for human exploration missions to the Moon and Mars. This year, the teams were asked to align their roadmap activities more closely to the capability gap study efforts to ensure priority areas are being adequately addressed.

EC also completed development of four small CubeSats in preparation for launch on Artemis I: BioSentinel, Near Earth Asteroid (NEA) Scout, Lunar IceCube, and Lunar Infrared Imaging (LunIR). Lunar IceCube and LunIR are NextSTEP partnerships in which costs are shared with industry and universities. These CubeSats will not only help answer strategic knowledge gaps associated with the Moon, asteroids, and effects of space radiation on biological systems, but will also develop capabilities for deep space CubeSats, enabling future missions for academia and industry. BioSentinel will study the effects of the deep space radiation environment on yeast deoxy-ribonucleic acid (DNA). NEA Scout will visit a small asteroid using a solar sail for propulsion. Lunar IceCube will search for water on the Moon with a broadband spectrometer. LunIR will test an advanced infrared sensor during a lunar flyby. The CubeSats were delivered to Kennedy Space Center (KSC) on July 14, 2021 and have been processed and installed on the Orion Stage Adapter, which has been fully integrated with the Space Launch System.

EC, in support of Gateway development, continued to advance work on common avionics and software capabilities that are the foundation for enabling the command, control, communications, and computing capabilities needed to operate a spacecraft and subsystems in LEO and beyond. In FY 2021, EC successfully infused technology developed by the Autonomous Systems and Operations project into Gateway. The Advanced Caution and Warning System (ACAWS), a fault management capability to help crew operate spacecraft in the presence of faults, was chosen by Gateway to be integrated into its flight software.

The Habitat group completed contract extensions for Appendix A: Habitation Systems under the NextSTEP Phase 3 Broad Agency Announcement (BAA). In Phase 3, NASA has asked companies to focus on habitat design concepts that could be used on the lunar surface or as a Mars transportation habitat. These activities will be funded under HERA in FY 2023.

A new activity called Project Polaris began with the selection of 10 proposals for small projects performed by the NASA centers. These projects will fill capability gaps and provide hands-on experience to early career NASA employees to transfer knowledge to the next generation of scientists, engineers, and technology project managers.

WORK IN PROGRESS IN FY 2022

EC habitation work will continue to deliver the fundamental capabilities and systems to provide astronauts a place to live and work in space. In addition to continuing ISS flight demonstrations initiated prior to FY 2022, EC, in partnership with the ISS, plans to complete flight hardware and demonstrate prototype systems and sub-systems on the ISS, including the Spacecraft Atmosphere Monitor (SAM) 2, Exposed Root On-Orbit Test System (XROOTS), and European Enhanced Exploration Exercise Device (E4D). SAM2 is currently scheduled for delivery in April 2022 and will be used to measure trace contaminants in the air. XROOTS will be used to investigate hydroponic and aeroponic techniques to grow plants without soil or other growth media. These findings will help identify potential methods available to produce crops on a larger scale for future space missions. EC will complete the E4D critical design review milestone. The E4D is a multi-purpose exercise device that the crew will use to maintain their fitness on long missions.

EC will also begin crew selection for the first Crew Health and Performance Exploration Analog (CHAPEA) simulated mission. CHAPEA is a series of analog missions that will simulate year-long stays on the surface of Mars to conduct simulated space walks and provide data on a variety of factors, including physical and behavioral health and performance.

EC will commence work on an integrated ECLS ground test system at Marshall Space Flight Center (MSFC). This effort will consist of refurbishing, upgrading, and integrating current test systems and the fabrication of new test systems. Procurements for flight like test hardware are in progress and will be in place by the end of FY 2022.

Radiation Protection activities include a demonstration of the Hybrid Electronic Radiation Assessor (HERA) on Artemis II. Radiation tolerant displays are being developed for Orion.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

EC will continue development of ground and flight experiments to investigate long duration support for landing humans on the Moon and establishing a sustainable, long-term presence on and around it. Upgrades to the Urine Processor Assembly (UPA) and Water Processor assembly (WPA) to increase reliably for exploration ECLSS will be completed and installed on ISS in FY 2023. Work on all other advanced habitation systems will also continue, with ISS flight demonstrations planned for 2025.

EC will conduct the first mission for the Crew Health and Performance Exploration Analog (CHAPEA) simulated Mars habitat located at Johnson Space Center (JSC). Four crew members will be confined to the habitat and surrounding "sandbox" simulating the Mars surface for 387 days, performing simulated extravehicular activity (EVAs), including virtual reality and a simulated Mars landscape. During the mission, crew members will be evaluated for performance based on diet and exercise throughout the mission.

EC will also continue building upon the current commercial engagement contracts to advance commercial habitation, avionics, flight software, life support, in-space refueling capabilities, and other commercial space industries.

Program Elements

HABITATION SYSTEMS

Habitation Systems delivers the fundamental capability to provide integrated life support systems, environmental monitoring, crew health, radiation protection, fire-safety, and systems to manage food, waste, clothing, and tools that enable astronauts to carry out NASA's mission in space and on other worlds. EC focuses on developing key habitation systems to enable the crews to live and work safely in space, with an art.

CREW HEALTH AND PERFORMANCE

These activities include development of countermeasures such as exercise equipment to maintain crew fitness on long missions; food systems such as crop production to provide nutritious food for the crew; development of diagnostic sensors for remote medical care; and models of human physiology to predict crew fatigue and injuries when performing EVA.

ROBOTIC PRECURSORS

In addition to the four CubeSats that will be launched on Artemis I, the Exploration Capabilities Program is developing small robotic spacecraft and remote sensing instruments to search for lunar resources.

Program Schedule

Date	Significant Event
Oct 2021	Begin Operations of 4-bed CO2 Scrubber on ISS
NET May 2022	Launch Artemis I CubeSats: BioSentinel, NEA Scout, LunIR, and Lunar IceCube
Jul 2022	Complete assembly of E4D Vibration Isolation System (VIS) flight unit
Aug 2022	Complete ECLSS integrated test plan; initiate procurements and begin test facility preparations
Aug 2022	CHAPEA Crew Selection
Sept 2022	Fire Safety: Conduct CDR for Commercial Lunar Payload Services (CLPS)

Program Management & Commitments

Directorate's Associate Administrator delegated management authority, responsibility, and accountability to the EC division at NASA Headquarters. EC Division establishes overall direction and scope, budget, and resource allocation for activities implemented by the NASA centers.

Program Element	Provider
Habitation Systems	Provider: NASA Centers Lead Center: Headquarters (HQ) Performing Center(s): JSC, MSFC, Ames Research Center (ARC), Glenn Research Center (GRC), Langley Research Center (LaRC), KSC, and Jet Propulsion Laboratory (JPL) Cost Share Partner(s): Bigelow Aerospace, Boeing, Lockheed Martin, Orbital ATK, Sierra Nevada, NanoRacks (NextSTEP), Dynetics, and UTAS
Crew Health & Performance	Provider: NASA Centers Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): N/A
Capabilities Maturation	Provider: NASA Centers Lead Center: JSC Performing Center: JSC Cost Share Partner(s): N/A
Robotic Precursors	Provider: NASA Centers Lead Center: HQ Performing Center(s): MSFC, JPL, ARC Cost Share Partner(s): N/A

Acquisition Strategy

Each year, EC evaluates how the portfolio aligns with human exploration priorities and technology gaps and either terminates or realigns activities that do not demonstrate adequate progress. EC also adds new activities to the portfolio, as appropriate. EC will continue to utilize this process to identify and evaluate risk-reduction activities needed in support of Gateway, HLS, and ACSC. EC strives to maximize specialized skills within the civil service workforce, but it may also utilize a small amount of contractor effort in areas where NASA can leverage external skills and knowledge in a cost-efficient manner. EC will also use the Small Business Innovation Research (SBIR) program to engage small businesses for risk reduction and technology maturation. EC continues the use of competitively selected external awards and industry collaborations. Upgrades to existing ISS life support systems will use existing contracts.

EXPLORATION CAPABILITIES

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Habitation Systems: Brine Water Processor	Paragon	Tucson, AZ; MSFC
Habitation Systems: Thermal Amine CO2 Scrubber	Collins Aerospace	Windsor Locks, CT
Habitation Systems: Oxygen Generation Assembly	Collins Aerospace	Windsor Locks, CT
Habitation Systems: Water Processor Assembly	Collins Aerospace	Windsor Locks, CT
NextSTEP Broad Agency Announcement Awards	Boeing, Bigelow Aerospace, Lockheed Martin, Orbital ATK, and Dynetics	JSC; MSFC; KSC

INDEPENDENT REVIEWS

EC undergoes quarterly Directorate Program Management Council reviews, and periodically, representatives from the Office of Chief Engineer, the Office of Safety and Mission Assurance, and the Office of Chief Financial Officer will assess EC performance during Agency-level Baseline Performance Reviews (BPR). In addition, EC provides briefing reports to, and seeks feedback on planning and development activities from, the NASA Advisory Council, Human Exploration and Operation Committee and the Technology Committee.

SPACE OPERATIONS

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
International Space Station	1,321.6	1,327.6	**1,307.5**	1,289.9	1,302.1	1,302.5	1,302.9
Space Transportation	1,871.9	1,770.2	**1,759.5**	1,798.8	1,848.7	1,889.2	1,914.8
Space and Flight Support (SFS)	890.3	947.2	**975.0**	1,031.7	1,053.1	1,020.1	948.6
Commercial LEO Development	18.1	102.6	**224.3**	228.2	229.4	302.1	435.0
Exploration Operations	0.0	0.0	**TBD**	832.9	972.3	1,037.2	1,070.5
Total Budget	**4,101.9**	**4,147.6**	**4,266.3**	**5,181.4**	**5,405.6**	**5,551.1**	**5,671.8**

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The FY 2023 President's budget request for NASA includes authority to transfer funds in FY 2023 from Orion Multi-purpose Crew Vehicle to Exploration Operations for Orion Production and Operations, up to $718 million, contingent on assessments following Artemis I.

SPACE OPERATIONS

SPACE OPERATIONS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
International Space Station	1,321.6	1,327.6	**1,307.5**	1,289.9	1,302.1	1,302.5	1,302.9
Space Transportation	1,871.9	1,770.2	**1,759.5**	1,798.8	1,848.7	1,889.2	1,914.8
Space and Flight Support (SFS)	890.3	947.2	**975.0**	1,031.7	1,053.1	1,020.1	948.6
Commercial LEO Development	18.1	102.6	**224.3**	228.2	229.4	302.1	435.0
Exploration Operations	0.0	0.0	**TBD**	832.9	972.3	1,037.2	1,070.5
Total Budget	**4,101.9**	**4,147.6**	**4,266.3**	**5,181.4**	**5,405.6**	**5,551.1**	**5,671.8**
Change from FY 2022 Budget Request			**118.7**				
Percent change from FY 2022 Budget Request			**2.9%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The FY 2023 President's budget request for NASA includes authority to transfer funds in FY 2023 from Orion Multi-purpose Crew Vehicle to Exploration Operations for Orion Production and Operations, up to $718 million, contingent on assessments following Artemis I.

NASA astronauts Kate Rubins (left) and Jeff Williams (right) are shown here preparing to grapple the SpaceX Dragon supply spacecraft from aboard the International Space Station.

The Space Operations account is dedicated to continued support of ISS operations and research in low-Earth orbit (LEO) that enables future exploration and advance discoveries that benefit life on Earth, while laying the foundation for America to maintain a constant human presence and develop a commercial economy in LEO. Beginning with this budget, Space Operations will also provide operations support for future Artemis Missions. Space Operations is comprised of the International Space Station (ISS), Space Transportation, Space and Flight Support, Commercial LEO Development and the new Exploration Operations themes. Collectively these themes are developing American-led space infrastructure enabled by a commercial market, enhancing space access and services to both Government and commercial entities, and researching and developing capabilities to safeguard our astronaut explorers. These activities, which support existing and future space operations for both NASA and non-NASA missions, are catalysts for economic development. Additionally, these activities advance scientific knowledge and foster new technologies that improve our lives. The activities in this account are managed by the Space Operations Mission Directorate, which was created during a reorganization approved in 2021.

ISS is an example of American leadership in global space exploration, enabling a U.S.-led multinational partnership to advance shared goals in space. As a testbed for deep space exploration, ISS is helping us learn how to keep astronauts healthy during long-duration space travel and demonstrating technologies for human and robotic exploration beyond LEO, to the Moon, and to Mars. ISS enables commercial industry, academic institutions, U.S. Government agencies, and other diverse users to access a unique research platform for developing and demonstrating new technologies, treatments, and products for improving life on Earth.

Under the Space Transportation theme, the Crew and Cargo Program manages transportation services provided by both international partners and domestic commercial providers. Through the program, NASA has greatly strengthened U.S. competitiveness by awarding ISS cargo resupply contracts to multiple vendors. Through this program, NASA continues to advance commercial spaceflight and support American jobs. The Commercial Crew Program (CCP) is developing and operating safe, reliable, and affordable crew transportation systems capable of carrying humans to and from the ISS and other destinations in low-Earth orbit. Working with industry to develop and provide human transportation services to and from space lays the foundation for more affordable and sustainable future human space transportation. These partnerships bolster American leadership in space, have ended our sole reliance on foreign providers for crew transportation services, help stimulate the American aerospace industry, and allow NASA to focus on building the capabilities and expertise necessary for missions to the Moon and Mars.

The Space and Flight Support Theme (SFS) continues to provide mission critical space communications, launch and test services, and astronaut training to support its customer missions. The Space Communications and Navigation (SCaN) Program provides communication to missions in LEO, including ISS, suborbital missions, and some lunar orbital missions, utilizing the Near Space Network. The Deep Space Network communicates with the missions most distant from Earth and will initially provide primary communications links to Artemis missions. SCaN is planning for expanded services for missions to the Moon, including lunar relay capability for missions that cannot communicate directly with Earth and enhanced position, navigation and timing services that are less dependent on tracking stations on Earth. The Communication Services Program focuses on demonstrating the feasibility of using commercially provided satellite communications (SATCOM) services to support NASA missions. The Launch Services Program provides expertise and active launch mission management for more than 70 NASA and other Government missions in various stages of development. The Rocket Propulsion Test Program manages a wide range of facilities capable of ground testing rocket engines and components under controlled conditions. The Human Space Flight Operations Program provides the training and readiness to ensure crew health and safety and mission success. To align their efforts with other operations organization in support of Artemis missions, the Human Research Program (HRP) is moving to SFS theme. Artemis missions will dramatically increase the scope of the challenges and demands that face NASA's astronauts. HRP is working to improve astronauts' ability to collect data, solve problems, respond to emergencies, and remain healthy during and after extended space travel.

NASA's Commercial LEO Development effort focuses on the development of a robust commercial space economy in LEO. It is stimulating the development of commercially owned and operated LEO destinations from which NASA can purchase services to meet NASA's enduring LEO human spaceflight requirements. As those commercial LEO destinations become available, and without a gap in a U.S. presence in LEO, NASA intends to implement an orderly transition from current ISS operations to the new commercial enterprise as laid out in NASA's ISS Transition Report (January 2022).

The Exploration Operations theme was created to manage production, sustainment, and mission operations of exploration hardware and capabilities developed in the Exploration Systems Development

Mission Directorate. As the various Artemis campaigns complete their initial development and production of hardware and/or capability and demonstrate their ability to move into production and sustainment mode, the funding for these programs will be provided in this theme. Initially, there are two programs under this theme: Orion Production and Sustainment, and Exploration Operations Program. Other Artemis campaign programs, including, Space Launch System (SLS), Exploration Ground Systems (EGS), Human Landing System and Gateway will transition in future budgets.

EXPLANATION OF MAJOR CHANGES IN FY 2023

On December 31, 2021, the Biden-Harris Administration announced the United States' commitment to extend ISS operations through 2030.

SCaN is increasing its infrastructure to support human and robotic exploration of the moon, including providing a lunar relay capability and enhanced position, navigation, and timing.

The Human Research Program will be transferred from Deep Space Exploration Systems Account to Space and Flight Support theme within the Space Operations Account beginning in FY 2023.

The Exploration Operations theme has been established, and operations funding from the Deep Space Exploration Systems account will begin to be transferred using the authority requested in the appropriations language beginning in FY 2023 (See Exploration Operations theme for a more detailed description). Orion Production and Sustainment has been transferred from Deep Space Exploration Systems account beginning in FY 2023.

For more information, go to: https://www.nasa.gov/directorates/space-operations-mission-directorate

INTERNATIONAL SPACE STATION PROGRAM

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
ISS Systems Operations and Maintenance	1,013.8	1,048.2	**1,041.7**	1,024.0	1,031.1	1,031.5	1,031.9
ISS Research	307.8	279.4	**265.8**	265.9	271.0	271.0	271.0
Total Budget	**1,321.6**	**1,327.6**	**1,307.5**	**1,289.9**	**1,302.1**	**1,302.5**	**1,302.9**
Change from FY 2022 Budget Request			**-20.1**				
Percent change from FY 2022 Budget Request			**-1.5%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The ten inhabitants of the International Space Station are gathered together in the Unity module for a meal and a portrait (October 8, 2021).

The International Space Station (ISS) is the largest and most complex space-based research facility ever constructed. ISS enables distinct research opportunities, including research vital to the Artemis human lunar exploration missions and future Mars human exploration programs. Returns from the investment in ISS are not limited to scientific discovery and technology advancement. The ISS international partnership is composed of five space agencies representing 15 nations, led by the United States. NASA's international partners include the Canadian, European, Japanese, and Russian space agencies. Engineers, scientists, and managers from around the world have directed their resources for the peaceful use of space and are now reaping the benefits to humanity. The ISS partnership uses global engagement and diplomacy to provide a cooperative foundation for the global enterprise of space exploration. The partnership allows members to collectively allocate resources and manage operational risks in a way that benefits all parties. ISS provides a high visibility opportunity for American leadership in low-Earth orbit (LEO).

ISS orbits the Earth about every 90 minutes and has been continuously occupied since 2000. November 2, 2021, marked the 21st anniversary of human occupation aboard the ISS. The U.S. Orbital Segment (USOS) is the portion of the ISS operated by the United States and its Canadian, European, and Japanese partners. Russia exclusively operates the Russian segment. The ISS spans the area of a U.S. football field (with end zones) and weighs more than 465 tons (930,000 pounds). Its solar arrays, which help power the vehicle, are longer than a Boeing 777's wingspan at 240 feet. The ISS has eight docking and berthing ports for visiting vehicles delivering crew and cargo. Orbiting Earth 16 times per day at a speed of 17,500 miles per hour, the ISS maintains an altitude that ranges from 230 to 286 miles. The complex has more

INTERNATIONAL SPACE STATION PROGRAM

livable room than a conventional five-bedroom house, with two bathrooms, fitness equipment, a 360-degree bay window, and state-of-the-art scientific research facilities. In addition to external test beds, the USOS houses three major science laboratories (United States Destiny, European Columbus, and Japanese Kibo). With the launch of the first U.S. commercial crew post-certification in November 2020, NASA increased its crew size on the USOS by one, to a total of four astronauts. On average, this doubled the total available hours of USOS crew time allocated to perform research on board the ISS each week.

The four major focus areas of activity for the ISS program include: (1) serving as a key stepping stone on the pathway to deep space exploration; (2) maintaining U.S. global leadership of space exploration; (3) enabling the development and advancement of a commercial marketplace in LEO; and (4) returning benefits to humanity on Earth through space-based research and technology development.

The ISS plays an essential role in facilitating the expanding sphere of human space exploration from LEO to the Moon (via the Artemis Campaign) and eventually to Mars. The ISS is currently the only microgravity platform capable of long-term testing of new life support and crew health systems, advanced habitation modules, and other technologies needed to expand NASA's exploration horizons. This research and development program will continue to focus on capabilities needed to maintain a healthy and productive crew in deep space, including the Gateway and future missions to the moon and Mars. Manifested or planned experiments and demonstrations to enable human exploration at the Gateway, lunar surface, and into deep space include: tests of improved long-duration life support technologies; advanced fire safety equipment; on-board environmental monitors; techniques to improve logistics efficiency; in-space additive manufacturing; advanced exercise and medical equipment; radiation monitoring and shielding; human-robotic operations; and autonomous crew operations. The facility enables scientists to identify and quantify risks to human health and performance and to develop and test preventative techniques and technologies to protect astronauts during extended time in space. The ISS platform and future commercial LEO destinations provide a rich environment for both basic and applied research.

NASA will continue research and technology efforts in LEO using the ISS to enable exploration with humans to the Moon and to Mars, while continuing to perform research that benefits humanity and leads to a robust ecosystem in LEO. NASA is working to implement a stepwise transition of ISS from the current model of NASA sponsorship and direct NASA funding to a model where NASA is one of many customers purchasing services from a LEO human spaceflight enterprise via the Commercial LEO Development Program. NASA will transition from current ISS operations to this new model when these commercial platforms and services become available. In order to support that transition, the Administration has announced its commitment to extending ISS operations through 2030, after which the ISS is planned to be retired.

NASA and its partners use this unique asset to advance science, technology, engineering, and mathematics (STEM) education efforts to inspire youth to pursue those fields. Over 2.8 million U.S. students have designed, launched, operated, or used data from more than 800 student experiments launched to ISS. ISS also provides a unique opportunity for STEM inspiration through direct engagement between astronauts and students. ISS inspires future generations and helps foster greater interest in STEM careers.

INTERNATIONAL SPACE STATION PROGRAM

The ISS program aims to provide direct research benefits to the public through its operations, research, and technology development activities. As a National Laboratory, the U.S. segment of the ISS enables Government agencies, academia, and industry to utilize its unique environment and advanced facilities to perform investigations. The focus of the ISS National Laboratory (ISSNL) is to provide ISS access to academia, the commercial sector, and other Government agencies through partnerships, cost-sharing agreements, and other arrangements for research, technology development, LEO commercialization, and education. Observing from and experimenting aboard ISS provides the opportunity to learn about Earth, life, and the solar system from a very different perspective. ISS serves as an innovation laboratory for experiments that cannot be accomplished on Earth. Earth observation instruments on ISS expand our Nation's understanding of the climate and carbon cycle. It also allows other NASA mission directorates to conduct research and demonstrate technologies. This includes technology demonstrations sponsored by the Space Technology Mission Directorate and basic and Earth Science research funded by the Science Mission Directorate. The results of the research completed on ISS can be applied to many areas of science, improving life on Earth, fueling American innovation and enhancing U.S. overall economic competitiveness, and furthering the experience and increased understanding necessary to journey to other worlds.

For more on the ISS program, go to: https://www.nasa.gov/mission_pages/station/main/index.html

EXPLANATION OF MAJOR CHANGES IN FY 2023

On December 31, 2021, the Biden-Harris Administration announced the United States' commitment to extend ISS operations through 2030.

The purpose of extending ISS is to enable continuation of the groundbreaking research being conducted in this unique orbiting laboratory through the rest of this decade.

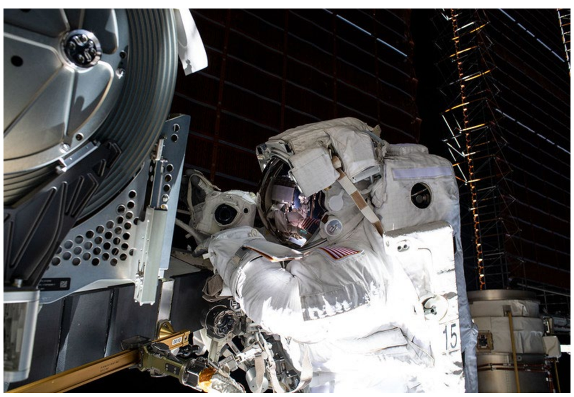
ISS SYSTEMS OPERATIONS AND MAINTENANCE

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**1,013.8**	**1,048.2**	**1,041.7**	**1,024.0**	**1,031.1**	**1,031.5**	**1,031.9**
Change from FY 2022 Budget Request			**-6.5**				
Percent change from FY 2022 Budget Request			**-0.6%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



NASA spacewalker Shane Kimbrough works to complete the installation of the second roll out solar array on the International Space Station's Port-6 truss structure (June 25, 2021).

The International Space Station (ISS) is a complex research facility and human outpost in low-Earth orbit (LEO) developed in a collaborative, multinational effort led by the United States with partners in Canada, Europe, Japan, and Russia. It is supported by the commercial industry via the Crew and Cargo Program and Commercial Crew Program (CCP). The facility's primary goals are to advance exploration of the solar system, enable unique scientific research, and promote commerce in space with industry partners as new commercialization concepts are explored. The ISS Systems Operations and Maintenance (O&M) project supports vehicle operations in the harsh conditions of space with constant, around-the-clock support. The ISS systems operate in extreme temperatures, pressures, and energies that challenge engineering techniques with minimal margin for error. The risks associated with operating the ISS are significant and must be effectively managed to protect against catastrophic consequences to mission success and human life. Successful risk mitigation activities on ISS in LEO pave the way for a more successful Artemis Campaign and missions to Mars.

Safely operating the ISS in the severe conditions of space and ensuring the crew always have a sufficient supply of food, water, oxygen, and repair parts demands precise planning and logistics. The 465-ton vehicle requires routine maintenance and is subject to unexpected mechanical failures, given its highly complicated systems and the harshness of space. Resolving problems can be challenging and often requires the crew to make repairs in space with support from ground teams on Earth. Astronauts aboard the ISS must rely on the materials available to them on board. This requires the support team on Earth to monitor and meticulously plan for replacement parts and consumables, such as filters and gases, as well as Orbital Replacement Units (ORUs) like the Inlet De-ionizing Bed, Microbial Check Valves, and Multi-Filtration Beds, which are key components of the Regenerative Environmental Control Life Support

ISS SYSTEMS OPERATIONS AND MAINTENANCE

System (Regen ECLSS). The coordination and support necessary for the ISS crew to live and work comfortably in space requires intensive Earth-based mission operations. Ground teams continually monitor ISS performance, provide necessary vehicle commands, and communicate with the crew.

Even before the astronauts leave Earth, the ISS Systems O&M project, in conjunction with the Human Space Flight Operations program, provides the crew training to prepare them for their stay aboard the ISS. One example includes operation of the Neutral Buoyancy Laboratory, an indoor underwater training facility, where astronauts, in a safe environment, can simulate specific extravehicular (EVA) activities to repair, replace, or install new instruments and operational systems. During training exercises, neutral-buoyancy diving is used to simulate the weightlessness of space operations. To achieve this effect, suited astronauts or pieces of equipment are lowered into the pool using an overhead crane and then weighted in the water by support divers so that astronauts experience minimal buoyant force and minimal rotational moment about their center of mass.

The ISS program considers all aspects of the mission when developing operations plans to meet program objectives. These include scheduling crew activities, choreographing docking and undocking of visiting crew and supply ships, evaluating supplies of consumables, managing flight plan variability, and resolving stowage issues. The ISS Systems O&M project ensures the ISS is always operational and available to perform its research mission.

Because the ISS is an international partnership, program decisions are not made in isolation. Rather, they require collaboration with multiple countries to ensure all technical, schedule, and resource supply considerations are taken into account. The experience NASA is gaining through integration with its ISS partners is helping the Agency to better prepare for future programs in human space exploration, such as on the Gateway or the lunar surface.

A critical component of the ISS Systems O&M project is immediate emergency services and analyses conducted by mission control teams on Earth, known as vehicle and program anomaly resolution. Engineers and operators diagnose system failures and develop solutions, while program specialists respond to changing program needs and priorities through re-planning efforts. These teams ensure appropriate redundancy, training, and procedures are in place to respond to any type of failure at any time. The project requires sparing and repairing nine highly complex on-orbit systems made up of hundreds of unique ORUs. Additionally, software sustainment manages and executes millions of lines of flight code to support operation and control of the ISS.

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

ACHIEVEMENTS IN FY 2021

The ISS Systems O&M project continued to maintain resources both on-orbit and on the ground to operate and utilize the ISS. The ISS Systems O&M project funded Mission Control Center operations monitoring the safety of crew and integrity of ISS 24/7 (Other MCC activities are funded by the programs they support). This is required to maintain success in providing all necessary resources, including power,

ISS SYSTEMS OPERATIONS AND MAINTENANCE

data, crew time, logistics, and accommodations, to support research while operating safely with a typical crew of seven astronauts, four USOS crew, and three Russian crew.

One overarching accomplishment is the successful navigation of ISS Operations through the COVID-19 pandemic. Operations on-orbit and Earth continued 24/7 and the ISS program successfully pivoted and quickly adjusted to the practices required to continue working as safely as possible.

The ISS Systems O&M project supported the arrival and departure of 13 flights, both domestic and international crew and cargo missions, to the ISS. This resulted in supporting almost one flight per month. Each flight required extensive planning and analyses to support on-orbit operations, as well as launching, docking, undocking, berthing, unberthing, deorbiting, packing, manifesting, hardware processing, and on-orbit configuration.

NASA ground teams continued to monitor overall vehicle health and oversee general maintenance and performance of all the ISS vehicle systems, including command and data handling, communication and tracking, crew health care, environmental control and life support, electrical power, extravehicular activities (EVAs), robotics, flight crew equipment, propulsion, structures and mechanisms, thermal control, guidance, navigation, and control. These individual teams worked together to support the crew in quick resolution of several unexpected anomalies, including continued support of ISS atmosphere leak source identification and mitigation.

In FY 2021, the team supported nine USOS EVAs. The Columbus module and several camera and wireless communication systems on ISS were upgraded. Five EVAs were completed to work towards the installation of six new ISS Roll Out Solar Arrays (IROSA), two of which were completed in FY 2021. The combination of the eight original arrays and the smaller, more efficient, new arrays will provide a 20 to 30 percent increase in power for space station research and operations. This upgrade ensures that the ISS will be able to support the anticipated power demand of future utilization and commercialization activities while preserving the expected increase in research and exploration technology demonstrations for Artemis and beyond.

Astronauts completed four series of Spacesuit Evaporation Rejection Flight Experiment (SERFE) runs on-orbit with a similar unit on the ground for comparison. SERFE is representative of the advanced EVA Thermal Loop architecture with flight-like pumps, flow control, and dual relief valves.

FY 2021 contained ISS advances in software vital to its on-orbit safety and day-to-day operations. The software updates included completion and transition on-orbit to R19 (supports Exploration ECLSS, four bed Carbon Dioxide scrubber, and Lab starboard water vent valve modification). Personal Computer (PC) installation updates were performed via the Joint Station LAN (JSL). This update allows the software to be uplinked to ISS via Ku-band wireless communications links. The updates are then transferred to individual PCs via an Ethernet connection, which reduces manifest needs and crew time requirements as well as increases the amount of payload data that can be recorded/distributed. The crew also completed 31 joint software tests. FY 2021 also saw the beginning development of software release R21, which includes JAXA/HTV-X support, and the ability to maintain Ku-band link through a Command, and Control computer transition. The program delivered six IT security patches to meet NASA and other Government security mandates and deployed additional Arcturus DAN boxes to support ISS technology demonstrations.

ISS SYSTEMS OPERATIONS AND MAINTENANCE

In the Avionics area, ISS continued external wireless connection upgrades which converted two external High Definition (HD) cameras to also serve as a wireless communication link, improving the Joint Station Local Area Network (LAN) Robustness. Other improvements included: installation of multiple Gigabit Ethernet cable that runs throughout the US modules and to the IP modules; additional edge router for redundancy and replacement of crew headsets with modern off-the-shelf headsets; ISS vehicle and hardware successes included the delivery of the Vascular Contingency Medical Kit for treatment of venous thromboembolism and one new Cupola scratch side pane. The Crew Alternative Sleeping Accommodation was delivered and installed, which supports increased crew member compliment. Lastly, the program completed build, delivery and launch of IROSA Wings 1-2 and successfully installed them on orbit to augment ISS Power Channels 2B and 4B.

WORK IN PROGRESS IN FY 2022

Throughout the year, NASA ground teams will continue to monitor overall vehicle health and oversee general maintenance and performance of all the ISS vehicle systems. The ISS Systems O&M project will continue to manage resource requirements and changes, including vehicle traffic, cargo logistics, stowage, and crew time. The ISS Systems O&M project is expected to support at least two U.S. Commercial Crew post-certification missions, as well as U.S. Crew test flight, the first Private Astronaut Mission, four U.S. Commercial Resupply Services cargo flights, three Progress flights, four crewed Soyuz flights, and one Russian hardware flight.

The program plans to support eight Russian EVAs and six U.S. EVAs in FY 2022. Two EVAs are scheduled to be completed in Increment 66 (March 2022) to prepare for IROSA installation on the 3A power channel and a Radiator Beam Valve Module Jumper EVA task. This series will also remove and replace an external camera. Another double EVA is scheduled for late Inc 67 (August 2022) to perform the final IROSA preparation for the 1A and 3B solar array power channels. The crew will continue to test the SERFE demonstration payload until its planned return on SpX-25 vehicle (June 2022); which includes a total of 25 simulated EVAs.

In FY 2022, ISS continues to develop and install software vital to its on-orbit safety and day-to-day operations. The planned software updates include completion and transition on-orbit to R20, which supports the Advanced Oxygen Generation Assembly and relocation of the European Space Agency (ESA) Life Support Rack, and the Oxygen Generator System. The updates include the capability to allow Ethernet devices to receive data from the Command Control Software on the 1553 LAN. Forty-two tests are planned, including 28 to support commercial crew/cargo flights, 12 for integrated R20/R21 testing, and two to support the Commercial LEO Development Program activities. The majority of these tests will be performed remotely with our International Partners and Commercial/Cargo vehicle providers. Software development for R22 will be started which includes updated encryption algorithms for the ISS Forward Link, the relocation of the Pressurized Mating Adapter (PMA) in preparation for the arrival of the commercial element, and the capability allowing CCS to receive data from devices on the Ethernet LAN. ISS will also be developing and deploying a specific virtual private network devoted to the Private Astronaut Mission crew and future space flight participants. This will provide additional controls, separate from the ISS-crew and will be starting the prototype for an ISS server for the Space Station Computer (SSC) network, which will consolidate the ever-growing SSC hub into a single device.

ISS SYSTEMS OPERATIONS AND MAINTENANCE

In the Avionics area, External Wireless Communication (EWC) expansion will continue with the conversion of two remaining external HD cameras to provide additional wireless communication for payloads and EVAs. Ku-band Space to Ground Transmitter Receiver Controller (SGTRC) spares builds will be completed, and all flight units delivered. JSL robustness improvements are to be activated which include redundant routers and interfaces to downlink/visiting vehicle comm links and eliminate bottlenecks. Optical communication will establish a one Gig interface from the JSL to the Integrated Laser Communications and Relay Demonstration, Low-Earth-Orbit User Modem, and Amplifier Terminal (ILLUMA-T) JEM location providing enhanced data capabilities on ISS. New digital still cameras for ISS and HoloLens deployment which will support REMOTE Guider capability as a crew time saver.

The Supplemental Heat Evaporative Cooler is to be delivered. Once installed it will retire a top program risk “Inability to perform USOS EVA to repair the ISS in case of the Dual External Active Thermal Control Systems (EATCS) Loop Failure.” Also, within the power generation and collection upgrades, the remaining three IROSA Wings are to be finished and delivered to NASA.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

The ISS Program will continue to support CCP and its commercial crew providers to ensure any challenges with the initial missions are addressed with minimal impact to ISS operations and research. NASA plans to work with international partners to maintain a continuous ISS crew member capability by coordinating and managing resources, logistics, systems, and operational procedures. The ISS Systems O&M project will continue to manage resource requirements and changes, including vehicle traffic, cargo logistics, stowage, and crew time. In addition to providing anomaly resolution and failure investigation (as needed), they plan and provide real-time support for activities, such as EVAs and visiting vehicles. The ISS Systems O&M project plans to support the launch of approximately 15 flights in FY 2023.

The team is currently planning two USOS EVAs to install the IROSA Wings on the 3A and 4A power channels in November and one Russian EVA. The ISS software team is planning to transition to R21 version of ISS software, and launch and deploy the Forward Link enhancement to improve the security of the command links. In addition, optical communication between the ISS and ground systems via ILLUMA-T and LCRD using Delay Tolerant Networking will be enabled.

PROJECT SCHEDULE

The table below provides a schedule for FY 2022 and FY 2023 completed and planned EVAs. The ISS conducts near-term, real-time assessments of EVA demands, along with other program objectives, to efficiently plan all required ISS activities. NASA remains postured to conduct EVAs on short notice in response to specific contingency scenarios. In addition, the ISS program balances routine maintenance EVAs against overall astronaut availability to maintain focus on utilization and research.

ISS SYSTEMS OPERATIONS AND MAINTENANCE

Date	Significant Event
Dec 2021	Two USOS EVAs
Jan 2022	Russian EVA
Mar 2022	Two USOS EVAs
Apr 2022	Two Russian EVAs
May 2022	Russian EVA
Jun 2022	Russian EVA
Aug 2022	Three Russian EVAs
Aug 2022	Two USOS EVAs
Nov 2022	Two USOS EVAs
Nov 2022	Two Russian EVAs
Jun 2023	Two USOS EVAs

Project Management & Commitments

While NASA maintains the integrator role for the entire ISS, each partner has primary authority for managing and operating the hardware and elements they provide. Within NASA, the Johnson Center (JSC) which is located in Houston, TX, leads the project management of the ISS Systems O&M.

Acquisition Strategy

The current Boeing vehicle sustaining engineering contract extends through September 2024. Requirements of this contract include sustaining engineering of U.S. on-orbit segment hardware and software, technical integration across all the ISS segments, end-to-end subsystem management for most of the ISS subsystems and specialty engineering disciplines, and U.S. on-orbit segment and integrated system certification of flight readiness.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
U.S. on-orbit segment Sustaining Engineering Contract	The Boeing Company	JSC

ISS SYSTEMS OPERATIONS AND MAINTENANCE

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	NASA Advisory Council/SOMD Subcommittee	Jan 2022	Provides independent guidance for the NASA Administrator.	The panel provided no new formal recommendations or findings for the ISS.	Mar 2022
Other	NASA Aerospace Safety Advisory Panel	Jan 2022	Provides independent assessments of safety to the NASA Administrator.	The panel provided no new formal recommendations or findings for the ISS.	TBD

ISS RESEARCH

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**307.8**	**279.4**	**265.8**	**265.9**	**271.0**	**271.0**	**271.0**
Change from FY 2022 Budget Request			**-13.6**				
Percent change from FY 2022 Budget Request			**-4.9%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Expedition 66 Flight Engineers (from left) Mark Vande Hei, Shane Kimbrough, Akihiko Hoshide and Megan McArthur, pose with chile peppers grown in space for the first time aboard the International Space Station for the Plant Habitat-04 investigation. (Oct. 29, 2021)

The International Space Station (ISS) is an orbiting platform that astronauts and researchers use to understand the effects of space on human health and to develop technologies to mitigate those effects that are a barrier to future human exploration missions. The unique microgravity environment enables scientific investigation of physical, chemical, and biological processes in an environment very different from Earth.

November 2, 2021 marked the 21st anniversary of continuous human presence in space aboard ISS. In that span, the orbiting platform has evolved into a dynamic laboratory that hosts an increasing variety of government and privately-owned science facilities, external testbeds, and observatory sites. The ISS provides the only current capability for human-assisted space-based research and is a foundation for efforts to expand commercial use of low-Earth orbit (LEO) and to enable a sustained U.S. presence in this region of space.

This budget line supports the ISS National Laboratory (ISSNL), which is dedicated to enabling non-NASA use of the ISS. The ISS Research budget also funds support for all research users of the ISS through NASA's multi-user systems support (MUSS).

In 2005, the United States segment of the ISS was designated as a National Lab by Congress. The 2010 Authorization Act subsequently designated that 50 percent of crew time, cargo up-mass, and access to research facilities on the ISS should be allocated for non-NASA use of the ISS. Non-NASA use of the ISS is managed through the ISSNL. NASA was directed by Congress to enter into a cooperative agreement with a single purpose non-profit, non-government organization (NGO) to manage non-NASA use of the ISS in cooperation with NASA. NASA selected the Center for the Advancement of Science in Space (CASIS) as the operating manager of ISSNL activities in 2011. The ISS National Laboratory Program allows non-NASA users to conduct Research and Development (R&D) activities on ISS that benefit life on Earth and foster commerce in space. Non-NASA users of ISSNL include other

ISS RESEARCH

Government agencies - such as the National Science Foundation (NSF), National Institutes of Health (NIH), and the Department of Defense (DoD) - as well as multiple academic institutions and commercial companies. Since 2012, more than 500 payloads have flown under the ISSNL allocation. For the past three fiscal years, more than 70 percent of payloads launched represent investigations from the private sector, fostering economic growth and expanding the low-Earth orbit.

MUSS provides strategic, tactical, and operational support to all ISS research, whether sponsored by NASA, international partners, or ISSNL. Through MUSS, the ISS Research budget supports the execution of the broader portfolio of research and technology development activities undertaken on the ISS and funded through other NASA organizations (e.g., Biological and Physical Sciences [BPS], Human Research Program [HRP], and Space Technology Mission Directorate [STMD]). ISS external research platforms enable research recommended by the National Academy Decadal and funded by NASA's Science Mission Directorate (SMD) to provide access to Earth and space vantage points. Taken as a whole, these R&D activities enable future human exploration, pioneer scientific discovery, expand our understanding of the universe and our home planet, and benefit our economy and life on Earth. MUSS continues to support new capabilities and technologies that benefit multiple ISS users and operation of in-orbit and ground control research facilities.

Research conducted aboard ISS, supported by this budget line item through MUSS and ISS National Lab activities, have made fundamental contributions to human knowledge and have advanced goals set by the National Academies of Science through a series of Decadal Surveys.

ISS research also supports the development of technologies of use in exploration campaigns such as Artemis, and longer-duration missions to Mars and beyond. ISS provides the best existing means to demonstrate technology and system readiness for use on a human occupied exploration vehicle by documenting performance in a spacecraft environment with humans-in-the-loop, piloting operational procedures and training requirements, determining logistics requirements, safety, and interoperability concerns with respect to overall space systems infrastructure. From an Environmental Control and Life Support Systems perspective, ISS is host to multiple long-duration flight experiments and projects; which include investigations in water purification, recovery and utilization; oxygen generation and filtration systems, carbon dioxide filtration systems, crop production and mitigation of known medical issues.

ISS Research also contributes to Agency efforts to spur economic growth of LEO and to enable a sustained U.S. presence in this region of space. NASA's plans for expanding activities in LEO build on and apply the lessons learned from over a decade of work and experience with private companies in ISS research. For example, research facilities onboard ISS continue to evolve from primarily Government funded and operated to privately owned and operated. Since 2012, privately owned research facilities have greatly increased the breadth and volume of ISS-supported research, with 18 such facilities in operation at the start of FY 2022 and private entities servicing 40 percent of ISS National Lab payloads. In addition, some 40 companies provide services as payload developers, guiding researchers to build and ship flight hardware to be executed on the station. These activities validate business models and expand the numbers of entities with experience in conducting business in space.

In an additional step for commerce in space, a new airlock, privately owned and operated, was integrated into the station and initiated service in FY 2021. The Nanoracks Bishop Airlock significantly increases the ability to transfer payloads to and from the stations external platforms and allows more small satellites to be deployed from station, while demonstrating the capabilities of a new airlock design for use in future exploration missions.

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

ACHIEVEMENTS IN FY 2021

FY 2021 saw new research facilities come online, new capabilities piloted, an increase in crew hours dedicated to science, and new solar panels add to the stations power capacity.

BioServe's Space Automated Laboratory Incubator (SALI), which will be used to incubate biological experiments in space, was validated and entered into service, increasing research capacity, and adding another commercial facility on the ISS. Additionally, two commercial facilities from Redwire Space launched to the ISS for validation. The Redwire Turbine-Ceramic Manufacturing Module (T-CMM) is designed to manufacture superior turbine components in microgravity with improved performance for aerospace applications. The Redwire Industrial Crystallization Facility (ICF), developed in part with funding from NASA's Small Business Innovation Research (SBIR) program, is an in-space manufacturing facility designed for the growth and formulation of large (centimeter-scale) single crystals and other exotic materials of industrially relevant size and quality. Following successful demonstrations, the T-CMM and ICF will be available for use by commercial customers.

FY 2021 also saw an increasingly diverse portfolio of commercial, fundamental science, and technology demonstration investigations conducted. The ISS Research budget supported, either directly or through MUSS integration services, nearly 400 active investigations across all ISS partners. NASA and the ISS National Lab combined to sponsor almost 200 U.S. research investigations. These totals included 88 payloads for the ISS National Lab.

Examples of fundamental research included:

- Studies of Bose-Einstein condensates using one of the stations newer research facilities, NASA Cold Atom Laboratory (CAL). CAL supports studies that require atom-interferometry measurement capability, a first of its kind in LEO. Atom interferometry can be used to precisely measure a host of phenomena including gravity, acceleration, rotation, electric fields, magnetic fields, and chemical interactions (see: https://www.jpl.nasa.gov/missions/cold-atom-laboratory-cal).
- Data from tests conducted for the Cool Flames Investigation with Gases (CFI-G), sponsored by the ISS U.S. National Lab and the National Science Foundation, showed the presence of cool flames for the first time using gaseous fuel. The discovery of cool flames in 2012 aboard the ISS, spawned a rapidly growing research field into their nature. Cool flames are difficult to study in Earth's gravity, but their unique chemistry may hold the key to more efficient and cleaner running combustion engines

  (see: https://www.nasa.gov/mission_pages/station/research/news/Cool_Flames_First_for_ISS).
- The Ring Sheared Drop (RSD) experiment team demonstrated a specialized device that uses surface tension rather than a solid container to hold liquids. It pins a drop of liquid between two rings and rotates one while keeping the other stationary to create shear flow between adjacent liquid layers. Researchers used the device to study protein aggregates called amyloid fibrils. These abnormal fibrous deposits found in organs and tissues are associated with neurodegenerative diseases such as Alzheimer's (see: https://science.nasa.gov/biological-physical/investigations/rsd).
- FY 2021 marked the 10th anniversary of the creation of the Center for the Advancement of Science in Space and the beginning of the organization's partnership with NASA to manage the ISS National

Lab. NASA is committed to collaborating with CASIS to manage the ISS National Lab as a resource for the American people and ensuring that it returns benefits to Earth and enables a robust LEO economy.

- The ISS National Lab continued to drive upward trends for industry involvement in supply, demand, and investment related to its R&D portfolio. ISS National Lab R&D activities in FY 2021 included projects from industry (such as Target, Bristol Meyers Squibb, GlaxoSmithKline, Lockheed Martin Corp.), startup companies funded in collaboration with Boeing, and research entities (such as Notre Dame University, Cornell University, Stanford University, and the Palo Alto Veterans Research Institute). Industry-driven activities included:
  - Colgate-Palmolive launched the first private-sector oral health care investigation to study unique plaque pathologies, examine gravity's effects on biofilm formation and oral dysbiosis (an imbalance in the oral microbial community), and compare responses to common oral care agents. Results could help to create more effective products for consumers on Earth.
  - Eli Lilly and Company initiated an experiment to examine the effects of gravity on the physical state and properties of freeze-dried pharmaceutical products. Results could help Lilly improve the chemical and physical stability of pharmaceutical products for patients on Earth.
  - ISS crew completed an investigation from Physical Optics Corporation to produce high-quality ZBLAN optical fibers in microgravity using the company's Orbital Fiber Optic Production Module.
  - FY 2021 was a record year for capital raising activity by startup companies in the ISS National Lab ecosystem. Based on publicly available data, $523 million of private and public capital as well as grant funding was raised during FY 2021 by startups that have completed a flight project with the ISS National Lab. These startups include Angiex, Emulate, Kernal Biologics, Lynk Global, Orbital Sidekick, Orbit Fab, Redwire Space, RevBio, Spire Global, and others. Since 2014, startups that completed projects sponsored by the ISS National Lab have raised more than $1.1 billion after completion of their flight. These funds were raised from public equity markets, venture/private capital, and via public and private grants.

Additional examples of accomplishments in FY 2021, representing both MUSS support and ISS National Lab efforts, include:

- The Redwire Regolith Print (RRP) study demonstrated 3D printing on the space station using a material simulating regolith, or loose rock and soil found on the surfaces of planetary bodies such as the Moon. Results could help determine the feasibility of using regolith as the raw material and 3D printing as a technique for on-demand construction of habitats and other structures on future space exploration missions.
- Four Bed CO2 Scrubber demonstrated a technology to remove carbon dioxide from a spacecraft. It is one of two carbon dioxide removal technology demonstrations for the space station's Exploration Environmental Control and Life Support Systems (ECLSS). Based on the current system and lessons learned from its nearly 20 years of operation, the Four Bed CO2 Scrubber includes mechanical upgrades and an improved, longer-lasting absorbent that reduces erosion and dust formation.
- Hewlett Packard Enterprise's Spaceborne Computer-2 (SBC-2) was installed and began operations on the ISS. SBC-2, following SBC-1's successful1.5-years of technology demonstration on the ISS, enables in-space data processing and analysis, providing quicker results that will facilitate iteration of experiments on station.

ISS RESEARCH

- Users of the ISS National Lab published 27 articles in peer-reviewed journals, including 11 related to NIH Tissue Chips in Space initiative and 11 to NSF/CASIS solicitations for transport phenomena, tissue engineering and mechanobiology. Topics covered included the first use of CRISPR technology to edit DNA in microgravity, stem-cell derived cardiac tissue research, flame-spread in confined spaces, and the formation and microstructure of ceramic-nanomaterial composites.
- A patent was filed by Emulate, Inc. related to the company's Intestine On-Chip system. This technology was developed in conjunction with Emulate's NIH-funded Tissue Chips in Space investigation examining microgravity's effects on immune response to disease-causing bacteria. The Intestine On-Chip system could be used to test therapeutic compounds to treat gastrointestinal disorders or diseases.
- Lockheed Martin Corporation (in collaboration with StemRad) tested the performance of the AstroRad radiation shielding vest on ISS crew members. AstroRad uses a selective shielding technology to protect organs that are most sensitive to radiation exposure. This ISS National Lab-sponsored investigation is beneficial not just to protect astronauts from radiation in space but also for people on Earth whose professions involve periodic exposure to radiation.
- STEM on Station (SoS) is an inclusive term for all ISS Related OSTEM activities initiated by NASA's Office of Education (see: http://www.nasa.gov/stemonstation and https://www.nasa.gov/stemonstrations). In FY 2021, SoS conducted 27 downlinks reaching 27 thousand elementary students, 13 thousand middle school students, 10 thousand high school students and 250 higher education students along with over 6 thousand formal and informal educators. One example included the Nanoracks for Student Payload Opportunity with Citizen Science (SPOCS). This opportunity led to the selection of five student teams to fly five payloads, contributing to research in either bacteria resistance or sustainability aboard station.
- Another example within SoS is the STEMonstrations program--they are a series of science demonstrations conducted by Astronauts on ISS. STEMonstration videos surpassed 1,000,000 total YouTube views – over 400,000 alone in FY 2021. These STEM demonstrations from the ISS, are short educational videos explaining popular K-12 STEM topics. These videos include a combination of ground-footage and footage captured aboard the International Space Station.
- Advancing X, Space Foundation, SpaceKids Global, Center for Applied Space Technology (CAST), Discovery Education, and the American Institute of Aeronautics and Astronautics (AIAA) all joined the Space Station Explorers program. In FY 2021, nearly two million people participated in partner programs with program content generating more than four million online impressions.
- A perspective paper was published in Preprints in FY 2021 discussing the goals and outcomes of a Biomanufacturing in Space Symposium that the ISS National Lab co-hosted. The symposium gathered thought leaders in the areas of tissue engineering, regenerative medicine, and space-based research. The symposium was the first step in developing a roadmap to establish a sustainable biomanufacturing market in LEO.
- Felix & Paul Studios, in association with TIME, "Space Explorers: The ISS Experience" is a groundbreaking virtual reality series which concluded filming on the ISS. The series recently won a Primetime Emmy for Outstanding Interactive Production at the recent 73rd Annual Emmy Awards.

For more information, go to: https://www.nasa.gov/mission_pages/station/research/index.html and https://www.issnationallab.org/

ISS RESEARCH

WORK IN PROGRESS IN FY 2022

Planned activities will continue to increase the number of commercial research facilities onboard the ISS. Those facilities will be enabling an increasingly diverse portfolio of commercial, fundamental science, and technology demonstration investigations. In the first half of FY 2022 alone, 208 investigations are scheduled to be active, 127 of which are NASA and ISS National Lab sponsored. Of these investigations, 80 are new.

Highlights of research planned, representing both NASA and the ISS National Lab efforts include:

- The Flow Boiling and Condensation Experiment (FBCE) aims to develop a facility for collecting data about two-phase flow and heat transfer in microgravity. Comparisons of data from microgravity and Earth's gravity are needed to validate numerical simulation tools for designing thermal management systems (see: https://www1.grc.nasa.gov/space/iss-research/iss-fcf/fir/fbce/).
- Techshot will relaunch the BioFabrication Facility (BFF)—the first American bioprinter in space. Originally validated onboard the ISS in 2019, the BFF was returned to Earth for refinements (see: https://www.nasa.gov/mission_pages/station/research/experiments/explorer/Facility.html#id=7599). Once the BFF is back on the ISS, multiple investigations are slated to leverage its capabilities, including projects to bioprint human cardiac muscle tissue and human vascular tissue, as well as a project from the DoD building on their previous investigation using the BFF to bioprint a partial human meniscus (cartilage of the knee).
- Uniform Protein Crystal Growth (UPCG) aims to grow a batch of near perfect nanocrystals of riboswitch RNA, which is responsible for switching individual genes on and off. Findings could help researchers better understand the process of gene switching, which has potential applications in biotechnology and medicine.
- L3 Harris will launch an ISS National Lab-sponsored project to advance understanding of photonic integrated circuit (PIC) technology, toward development of the company's new satellite constellations in LEO. A better understanding of the effects of radiation on PIC performance could enable the design of PIC technology with improved radiation tolerance.
- "Organs-on-Chips as a Platform for Studying Effects of Microgravity on Human Physiology: Blood-Brain Barrier-Chip in Health and Disease." A tissue chip investigation from Emulate, Inc. analyzes the effects of microgravity and other space-related stressors on the blood-brain barrier. The project uses fully automated tissue chip technology, a Blood-Brain Barrier-Chip, consisting of living neuronal, and vascular endothelial cells in a micro-engineered environment. Results may provide insight into the relationship between inflammation and brain function and a better understanding of neurodegenerative diseases such as Alzheimer's and Parkinson's.
- Procter & Gamble will launch their "Tide in Space" investigation under sponsorship of the ISS National Lab. Testing consumer products in space provides valuable insight to manufacturers about the performance limits of their products in vastly different environments. Results from this investigation will help to inform both Procter & Gamble and NASA about the benefits of this detergent technology for spot cleaning while conserving water.
- The NACHOS project validates a CubeSat-based hyperspectral imager (HSI) for imaging of trace gases such as NO2 associated with fossil fuel burning and SO2 emitted by volcanoes. This technology could lead to a constellation of many CubeSat-based HSIs, providing greater flexibility and coverage than traditional large-satellite instruments, at much lower cost.

- The Alternate Fecal Container (AFC) demonstrates using a soft-sided container to collect and store fecal deposits as part of the ISS's Universal Waste Management System (UWMS). The AFC is lighter weight and can launch in a collapsed configuration, reducing launch mass and supporting longer exploration missions.
- Merck Research Laboratories will launch a follow-on project to identify key variables in the crystallization of pembrolizumab, the active pharmaceutical agent in the cancer drug Keytruda®. Through their initial project, Merck was able to produce highly uniform, stable concentrated crystalline suspensions of pembrolizumab on the ISS and successfully translate their findings to ground-based drug processes. Results from this research could lead to improvements in the manufacture, storage, and delivery of pembrolizumab, which could reduce costs and improve patient quality of life.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

NASA will continue to innovate, implementing new processes for payload development and integration that are focused on sending investigations to ISS as soon as they are ready. The improved timelines offered by these processes better meet the demands of its users, resulting in quicker payload deliveries to ISS (within months in some cases). Thus, private sector users looking to leverage space-based activities to accelerate time to market for product enhancements have a rapid path from project concept to flight. This bolsters the value proposition for space-based R&D. Similarly, R&D sponsored by NASA, by private companies, or by non-NASA Government agencies can be executed within a timeline that enhances the relevance of the research projects. For these cutting-edge projects, scientific discovery and technological advancement moves quickly and will benefit by optimized timelines to flight.

Under the streamlined payload development and integration processes, the flight manifest for FY 2023 is still in development. However, upcoming investigations expected to fly in FY 2023 include:

- Tissue engineering and regenerative medicine to improve human health and longevity, and flight projects supported by other Government agencies, including both NIH and NSF, will explore a range of related topics from stem cell biology to 3D printing.
- The Atmospheric Waves Experiment (AWE), planned to launch in late 2022, will attach to the exterior of the ISS. From its space station perch, AWE will focus on colorful bands of light in Earth's atmosphere, called airglow, to determine what combination of forces drive space weather in the upper atmosphere. AWE is the first dedicated NASA mission designed specifically to characterize the properties of global mesospheric gravity waves (see: https://www.nasa.gov/press-release/nasa-selects-mission-to-study-space-weather-from-space-station).
- Multiple ISS National Lab-sponsored physical science projects funded by NSF, and projects selected and funded by the Boeing Technology in Space Prize with CASIS.
- Multiple projects awarded through ISS National Lab research announcements in the areas of in-space production applications and technology development/demonstration.
- Axiom's UNIGLO (Universal Glass Optics Manufacturing Module, Intelligent Glass Optics), flying under ISS National Lab allocation but funded by a NASA Small Business Innovation Research (SBIR), will join other investigations that examine fiber optic cable production in space. UNIGLO technology developed by Apsidal of Los Angeles that will melt ZBLAN glass and draw optical fiber on the ISS that is expected to surpass the quality of terrestrial manufactured fiber. ZBLAN is one of many exotic glasses that have much higher theoretical performance over commonly used silica-based

fibers in the very large telecom industry as well as specialty applications in defense, technology, and medical industries. Unfortunately, industry and Government use of these exotic glasses is limited to very short sections (~2 million or less) due to the challenges associated with crystallization when drawn in 1g as gravity induced material convection and sedimentation in complex glasses on Earth subsequently leads to unwanted crystallization, thus creating defects which reduce performance. Therefore, the microgravity environment of space is needed to achieve the performance near the theoretical limits for these heavy metal fluoride glasses. UNIGLO is capable of processing various types of complex glasses in space from which optical fibers, fiber lasers, magnetic fibers, super-continuum sources, capillary optics, and adiabatic tapers can be drawn. Market areas for products from this module include specialty fibers for low-loss and high bandwidth communications, high-power fiber-amplifiers, IR counter measures, supercontinuum sources, medical applications, remote sensing, X-ray optics, and laser processing.

- The ArgUS platform, capable of hosting multiple experiments on a single payload slot in the Bartolomeo External Science and Payload Hosting Facility on the ISS, is expected to become available in FY 2023. Through the ArgUS and Bartolomeo platforms, Airbus DS Space Systems aims to reduce the cost of conducting experiments in LEO, helping to foster commercial use of LEO and support new-to-space users with limited budgets who depend on the availability of space access and infrastructure.
- Three new ISS facilities from Redwire are expected to be commercially available in FY 2023: the Turbine-Ceramic Manufacturing Module (T-CMM), the Turbine-Superalloy Casting Module (T-SCM), and the Industrial Crystallization Facility (ICF).

Project Schedule

An increment, or expedition, is a period of time for ISS operations that spans from one crew return mission to another. Three to five expeditions typically span a calendar year and each consists of cargo ship arrivals and departures, extensive research investigations, as well as standard crew maintenance and logistical tasks. The table below provides a schedule for FY 2022 through FY 2023 completed and planned start dates for the upcoming increments to ISS.

Date	Significant Event
Nov 2021	Increment 66
Mar 2022	Increment 67
Sep 2022	Increment 68
Mar 2023	Increment 69
Sep 2023	Increment 70

Project Management & Commitments

The ISS Program Office meets commitments to international partners for utilization access under the ISS Intergovernmental Agreements and follows statutory guidance in the NASA Authorization Act of 2010 in providing access to on-orbit capabilities for ISSNL research. The ISS Program interfaces with ISSNL and

ISS RESEARCH

personnel from a wide variety of NASA organizations to integrate objectives into strategic plans and implement research.

Within NASA, mission directorates also prioritize their research investments for ISS based on exploration roadmaps for technologies needed to support NASA's exploration goals, the Human Research path to risk reduction, and recommendations from the relevant National Academies of Science decadal surveys. These are demonstrated in non-ISS budgets of HRP, some activities in STMD, and specific SMD projects including BPS.

Element	Description	Provider Details	Change from Formulation Agreement
MUSS	MUSS activities support all research on ISS (NASA sponsored and non-NASA sponsored)	Provider: ISS program and contractors Lead Center: Johnson Space Center (JSC) Performing Center(s): MSFC, ARC, GRC, KSC, JPL Cost Share Partner(s): N/A	N/A
ISSNL	Manages ISSNL through the National Laboratory Cooperative Agreement	Provider: Center for the Advancement of Science in Space (CASIS)	N/A

Acquisition Strategy

NASA awards contracts and grants for conducting research on ISS. NASA prioritizes ISS research based on an established Agency process that prioritizes NASA's use for exploration critical research needs (human research for exploration and technology research for systems to support long-duration lunar and Mars missions) followed by research that aligns with the National Academies' Decadal Surveys that are related to science that can be done in space. NASA manages non-NASA ISS research activities through the ISSNL in cooperation with CASIS and that research is prioritized separately from the NASA research. Peer review is practiced in each selection and is the means to ensure a high-quality research program. Engaging leading members of the research community to assess the competitive merits of submitted proposals is essential to ensuring the productivity and quality of ISS research.

MAJOR CONTRACTS/AWARDS

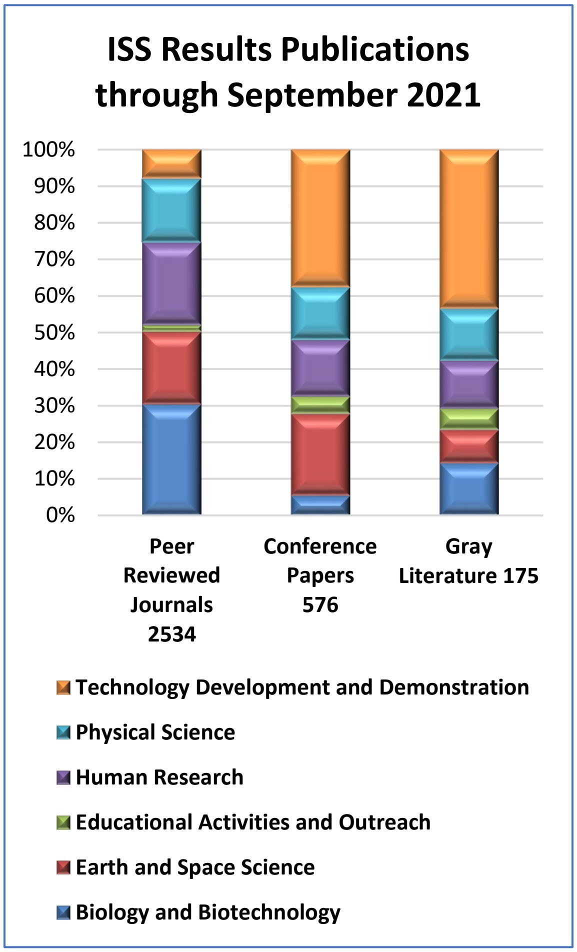
Element	Vendor	Location (of work performance)
Vehicle Sustaining Engineering Contract	The Boeing Company	Houston, TX
Huntsville Operations Support Center	COLSA Corporation	Huntsville, AL
Mission Operations and Integration (MO&I) Contract	Teledyne Brown Engineering	Huntsville, AL
ISSNL Management Entity	CASIS	Melbourne, FL

ISS RESEARCH

INDEPENDENT REVIEWS

Independent reviews for the ISS program as a whole are cited in the ISS O&M section of this document. There are no independent reviews planned that are unique to ISS research.

HISTORICAL PERFORMANCE

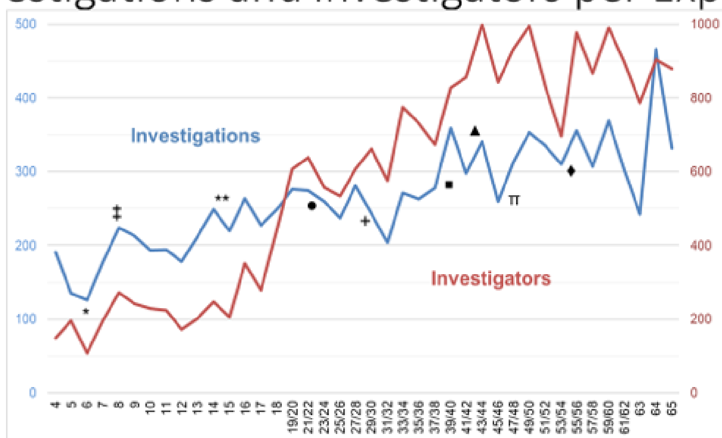


As of the start of Expedition 66, at the beginning of FY 2022, more than 4,600 investigators from 109 countries have performed more than 3,300 investigations and technology demonstrations utilizing ISS. As shown in the ISS Results Publications graph to the left, over 3,100 papers have been published in scientific journals and conference proceedings based on results of these investigations. In FY 2021 alone, more than 360 papers were published representing more than 10 percent of the total. This demonstrates the growing impact of ISS research results in the scientific community as ISS research capabilities have expanded.

The graphs below highlight the amount and diversity of research conducted on the ISS. The first shows the number of investigations by expedition and the type of investigations by category and country. The data for expeditions 0-62 has been approved by the ISS Mission Control Board, and expedition data 63 thru 65 includes estimates which are under review. Of particular interest is how the number of investigations by expedition has varied over history, as the fluctuation is influenced by crew and cargo transportation and number of crew members on board ISS.

ISS Research

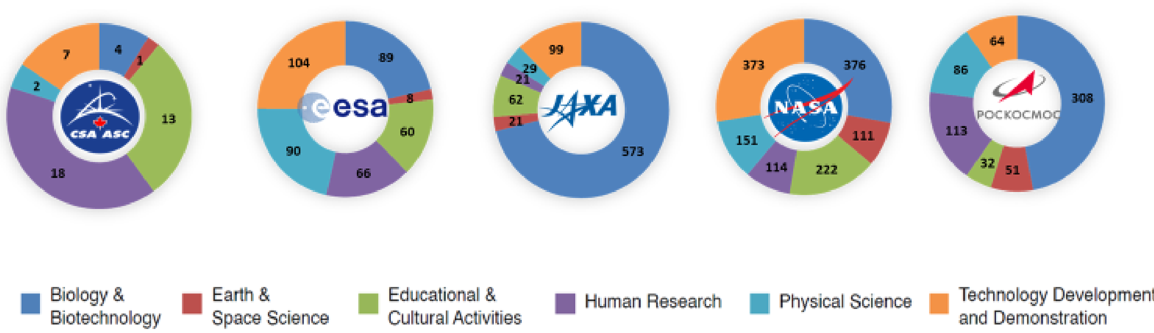
Expeditions 0-65 Estimated Investigations and Investigators per Expedition



* Post Columbia ‡ Japanese investigation surge in protein crystal growth **Shuttle Return to Flight ● 6 Crew
+ Final Shuttle Flight ■Commercial Resupply Flights Begin ▲ Loss of Orb-3 π Loss of 59P and SpX-7
◆ 4 USOS Crew and extended expedition;

Note: Expeditions 0-62 data validated, 63-65 estimates under review

Expeditions 0-65 Estimated Investigation per Agency



Note: Expeditions 0-62 data validated, 63-65 estimates under review

SPACE TRANSPORTATION

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Crew and Cargo Program	1,573.2	1,617.2	**1,642.0**	1,698.8	1,748.7	1,789.2	1,814.8
Commercial Crew Program	298.7	153.0	**117.5**	100.0	100.0	100.0	100.0
Total Budget	**1,871.9**	**1,770.2**	**1,759.5**	**1,798.8**	**1,848.7**	**1,889.2**	**1,914.8**
Change from FY 2022 Budget Request			**-10.7**				
Percent change from FY 2022 Budget Request			**-0.6%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Two U.S. spacecraft, the SpaceX Cargo Dragon (foreground) and the SpaceX Crew Dragon (bottom center), are pictured docked to the Harmony module's international docking adapters (September 12, 2021).

Space Transportation's objective is to transport U.S. astronauts and cargo safely to and from space, including the International Space Station (ISS). This theme includes the Commercial Crew Program (CCP) and the Crew and Cargo Program. Maintaining ISS requires a fleet of vehicles and launch locations to: transport astronauts, science experiments, critical supplies, and maintenance hardware; replenish propellant; and dispose of waste.

CCP partners with the U.S. commercial sector to develop and operate safe, reliable, and affordable crew transportation to low-Earth orbit (LEO). NASA awarded Commercial Crew Transportation Capability (CCtCap) contracts to Boeing and Space Exploration Technologies Inc. (SpaceX) in September 2014. Through its certification efforts, NASA will ensure the selected commercial transportation systems meet NASA's safety and performance requirements for transporting crew to ISS.

Within the Crew and Cargo Program, NASA purchases cargo transportation to ISS under Commercial Resupply Services (CRS) contracts with Northrop Grumman, Sierra Space (a subsidiary of Sierra Nevada Corp (SNC), and SpaceX. NASA has transitioned from purchasing crew transportation to ISS from the Russian Roscosmos State Corporation, known as Roscosmos, to purchasing from commercial providers Boeing and SpaceX. Beginning with the SpaceX commercial crew Demo-2 flight in May 2020, the United States is once again launching astronauts into space and to ISS. The first commercial crew service mission was the SpaceX Crew-1 flight on November 15, 2020. The Budget also supports other space transportation-related activities, such as integration work required to ensure that these visiting vehicles can safely dock or berth to ISS and the development of hardware such as the NASA docking system.

SPACE TRANSPORTATION

As of September 2021, NASA had allocated approximately $20.8 billion towards service providers under the commercial crew and cargo programs. These funds have supported the completion of two rockets, two cargo vehicles and one crew vehicle, the ongoing development of one other crew vehicle and one other cargo vehicle, and 39 successful cargo flights to ISS. Of that amount, NASA contributed $5.9 billion towards the development of the commercial crew and cargo systems. This is the amount NASA refers to as its "investment" in the systems. The $5.9 billion includes NASA's share of the commercial cargo development costs as well as all NASA Commercial Crew Program development costs (Commercial Crew Development [CCDev] Phases 1 and 2, the Commercial Crew Integrated Capability [CCiCap] initiative, Certification Products Contract [CPC], and CCtCap). The remaining $14.9 billion is the amount NASA has contracted for services (i.e., the transportation of cargo and crew to the ISS). This amount includes the current contract values for both CRS-1 and CRS-2 cargo contracts, as well as CCtCap crewed missions to the ISS. Within the current maximum contract value, NASA can still award another $8.5 billion under the CRS-2 contracts. Of the $20.8 billion NASA has allocated to these programs, $16.4 billion has been paid to the companies to date.

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

CREW AND CARGO PROGRAM

Formulation	Development	Operations

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**1,573.2**	**1,617.2**	**1,642.0**	**1,698.8**	**1,748.7**	**1,789.2**	**1,814.8**
Change from FY 2022 Budget Request			**24.8**				
Percent change from FY 2022 Budget Request			**1.5%**				

The Northrop Grumman Cygnus cargo vehicle is pictured in the grips of the Canadarm2 robotic arm after it was installed on the Unity module's Earth-facing port (August 12, 2021).

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Maintaining the International Space Station (ISS) requires a fleet of launch vehicles to sustain a constant supply line of both crew and cargo that is crucial to ISS operations and research. Deliveries not only provide science experiments, supplies, and maintenance hardware, but also rotate crewmembers, return research and equipment for repair, and dispose of waste.

The Crew and Cargo Program manages transportation services provided by both international partners and domestic commercial providers. NASA’s commercial service contracts to resupply the ISS have changed the way the Agency does business in low-Earth orbit (LEO). With these contracts, NASA continues to advance commercial spaceflight while simultaneously supporting the American jobs created by this industry.

Through FY 2020, NASA purchased cargo delivery to the ISS from Northrop Grumman (formerly Orbital ATK) and Space Exploration Technologies Inc. (SpaceX) under the original Commercial Resupply Services (CRS) contracts. These vehicles provided between 2,200 and 3,700 kilograms of cargo to ISS

CREW AND CARGO PROGRAM

Formulation	Development	Operations

with each mission. The cargo provided to ISS includes crew supplies, operations hardware, and numerous science research and technology demonstration investigations.

Northrop Grumman, SpaceX, and Sierra Space are working under the follow-on CRS-2 contracts with missions beginning in FY 2020. Under CRS-2, Sierra Space will launch CRS missions from Cape Canaveral, FL, as SpaceX does today. Both of these providers also have or will have the capability to return science experiments to Earth. SpaceX uses its Falcon 9 rocket to launch the Dragon-2 docking cargo vehicle, while Sierra Space will use United Launch Alliance's Vulcan rocket to launch its Dream Chaser Cargo (DCC) berthing vehicle. Northrop Grumman primarily launches its Cygnus berthing cargo vehicle on the Antares rocket from the Mid-Atlantic Regional Spaceport at NASA's Wallops Flight Facility (WFF) in Virginia. Northrop Grumman provides trash disposal and conducts additional experiments before the Cygnus spacecraft burns up in the atmosphere after leaving ISS. These capabilities enable studies of fire suppression, the deployment of small satellites at altitudes above the ISS, and other activities not suited for ISS on-board operation. The Crew and Cargo Program budget supports all milestone payments for these contracted flights to provide cargo transportation for a multitude of users, including transportation for National Laboratory science research payloads.

The Commercial Orbital Transportation Services Program used a series of fixed-price, milestone-based Space Act Agreements to support the development of several companies' efforts to develop commercial cargo resupply capabilities. As a result, NASA is now able to purchase these commercial services from several providers under the Crew and Cargo Program using fixed-price contracts, which have more predictable budget requirements than cost-reimbursable contracts, and which can provide cost savings to the Federal Government compared to other types of contracts. This arrangement has resulted in a stronger U.S. space launch industry, redundancy in the cargo resupply mission area that has increased mission assurance, and robust private sector employment. NASA is leveraging the lessons learned in this program to expand science and research capabilities that these vehicles provide for CRS-2 missions. The CRS contract vehicle has been used as an example by other programs, such as Gateway and the Human Lander System.

For years after the Space Shuttle was retired in 2011, crew transportation to ISS was provided using the Russian Soyuz vehicle. However, beginning with the SpaceX commercial crew Demo-2 flight in May 2020, the United States is again launching astronauts into space and to ISS. The Commercial Crew Program (CCP) manages these activities to develop and provide domestic crew transportation to the ISS under the Commercial Crew transportation Capability (CCtCap) contracts with Boeing and SpaceX. CCP is funding the first Post Certification Missions (i.e., crew missions) to the ISS for each provider; the Crew and Cargo Program is funding the second and all subsequent missions.

The Crew and Cargo Program also funds activities supporting visiting vehicles that provide transportation for the ISS, including integration activities.

CREW AND CARGO PROGRAM

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

ACHIEVEMENTS IN FY 2021

Northrop Grumman completed 11 mission milestones in support of six commercial resupply flights, including milestones for successful completion of three CRS-2 flights in FY 2021. SpaceX completed 15 mission milestones in support of nine commercial resupply flights, including milestones for successful completion of three CRS-2 flights in FY 2021. Northrop Grumman and SpaceX have completed all seven CRS-2 integration milestones required to demonstrate new contract capabilities and design enhancements to support science and payload research objectives. Sierra Space completed one ISS Integration milestone (GPS Navigation near ISS risk reduction test and FCC license review). No mission milestones were completed in FY 2021.

The program funded CCtCap contract milestones for post-certification crew missions that will be flown by Boeing and SpaceX. More information on CCtCap progress can be found under the CCP portion of this document.

The program supported two SpaceX Commercial Crew missions (Crew-1 and Crew-2) and two crewed Soyuz launches, one of which (63S) was partially funded by NASA as the Agency transitioned to commercial crew services. In addition, NASA signed a contract with Axiom Space of Houston (Axiom) to fly an astronaut on the remaining Soyuz launch (64S) with no exchange of funds. Additional information can be found in the Acquisition Strategy section. The program also supported two launches of Progress, a Russian cargo vehicle, and one Russian space station module deployment flight for the Multipurpose Laboratory Module, not funded by NASA.

WORK IN PROGRESS IN FY 2022

NASA expects four commercial resupply flights to deliver research and logistics hardware in FY 2022. Northrop Grumman plans to launch two flights and complete 11 mission milestones in support of six CRS-2 flights. SpaceX plans to launch two flights and complete 14 mission milestones in support of nine CRS-2 flights. Sierra Space plans to complete three mission milestones in support of two CRS-2 flights. Sierra Space will also complete one ISS integration milestone.

The program will also continue funding CCtCap contract milestones for post-certification crew missions with Boeing and SpaceX. SpaceX missions began in November 2020 after successful completion of the test flights and NASA certification. Boeing will be conducting additional test flights in FY 2022. More information on CCtCap progress can be found under the CCP portion of this document.

After the initial flights, the regular flight plan will provide for two commercial crew flights per year carrying four crew each flight. However, the first two flights for each provider may be scheduled in a shorter timeframe to reduce risk and accomplish more research. In addition, the program will support the

Formulation	Development	Operations

first Private Astronaut Mission (PAM) aboard ISS with Axiom Space of Houston (Axiom). The program will also support four Soyuz crew launches, three Progress cargo launches and one Russian space station module deployment flight that are not funded by NASA.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

The Crew and Cargo Program will enable continued research and technology development by providing a stable crew and cargo flight plan.

NASA expects five commercial resupply flights to deliver research and logistics hardware in FY 2023. Northrop Grumman plans to launch one commercial resupply flights and complete seven mission milestones in support of five CRS-2 flights. SpaceX plans to launch three commercial resupply flights and complete 14 mission milestones in support of eight CRS-2 flights. Sierra Space plans to launch its first CRS-2 flight and complete nine mission milestones in support of five CRS-2 flights. Sierra Space will also complete the remaining two integration review milestones towards completion of their vehicle testing and final safety review work. These resupply flights will be vital for delivering not only the day-to-day supplies needed, but also the experiments that will enable the astronauts to continue important research on ISS. The flights will also support the increased number of research and science investigations enabled by the additional astronauts once commercial crew is available.

The program will also continue funding CCtCap contract milestones for post-certification crew missions with Boeing and SpaceX. NASA is planning for at least two commercial crew missions annually. The flight schedule also includes two Soyuz crew launches, three Progress cargo launches, and one H-II Transfer Vehicle (HTV)-X, a Japanese cargo vehicle, that are not funded by NASA.

PROJECT SCHEDULE

Maintaining a regular rate of cargo delivery on a mix of NASA and international partner vehicles ensures the ISS can sustain nominal operations and maintenance, while allowing the program to respond to any anomalies that might occur. The table below shows scheduled ISS flight plans for FY 2022 and FY 2023. The Boeing Crew Flight Test (CFT) is not included as the date is currently under review. NASA funds SpaceX (SpX), Northrop Grumman (NG), and Sierra Space cargo missions, as well as Boeing and SpaceX crew missions. The planned spacing of the Commercial Crew and Soyuz crew rotation flights ensures a continuous crew presence on the ISS and smooth transitions between crews.

Date	Significant Event
Oct 2021	Soyuz 65S
Oct 2021	Progress 79P
Nov 2021	SpX Crew-3
Nov 2021	6R (Russian Proton launch of Russian Segment-Node)

CREW AND CARGO PROGRAM

Formulation	Development	Operations

Date	Significant Event
Dec 2021	Soyuz 66S
Dec 2021	SpX-24
Feb 2022	Progress 80P
Feb 2022	NG-17
Mar 2022	Soyuz 67S
Mar 2022	Axiom (Ax)-1 (PAM)
Apr 2022	SpX Crew-4
May 2022	SpX-25
May 2022	Boeing Orbital Flight Test -2 (OFT-2)
Jun 2022	Progress 81P
Aug 2022	NG-18
Sep 2022	Soyuz 68S
Fall 2022	SpX Crew-5
Oct 2022	SpX-26
Oct 2022	Progress 82P
Jan 2023	HTV-X1
Jan 2023	SpX-27
Feb 2023	NG-19
Feb 2023	Progress 83P
Feb 2023	Sierra Space DCC-1
Mar 2023	Soyuz 69S
Q2 FY 2023	Ax-2 (PAM)
Q2 FY 2023	Commercial Crew Mission
Jun 2023	SpX-28
Jul 2023	Progress 84P
Sep 2023	Soyuz 70S
Q4 FY 2023	Commercial Crew Mission

CREW AND CARGO PROGRAM

Formulation	Development	Operations

Project Management & Commitments

Johnson Space Center (JSC) is responsible for management of the Crew and Cargo Program.

Element	Description	Provider Details	Change from Formulation Agreement
Crew transportation	Commercial crew transportation will be provided by Boeing and SpaceX and managed by the Commercial Crew Program.	Provider: Boeing; SpaceX Lead Centers: JSC, KSC Performing Center(s): N/A Cost Share Partner(s): Canadian Space Agency (CSA), European Space Agency (ESA), and Japan Aerospace Exploration Agency (JAXA)	N/A
Cargo transportation	Northrop Grumman, SpaceX, and Sierra Space will provide cargo transportation to the ISS via the major contracts described below. JAXA will provide additional cargo transportation as part of the ISS partnership.	Provider: Northrop Grumman, SpaceX, Sierra Space, and JAXA Lead Center: JSC Performing Center(s): GSFC, KSC Cost Share Partner(s): CSA, ESA, and JAXA	N/A

Acquisition Strategy

The ISS program competitively procures all ISS cargo transportation services, excluding services obtained via barter with our international partners or nominal cargo transportation provided by Soyuz. On January 14, 2016, NASA competitively awarded CRS-2 contracts to Orbital ATK (now Northrop Grumman), Sierra Space, and SpaceX, with cargo transportation services that began in November 2019. Like the preceding CRS contracts, CRS-2 contracts are milestone-based, fixed-price, indefinite-delivery-indefinite-quantity (IDIQ) contracts.

In September 2014, NASA's CCP awarded CCtCap contracts to Boeing and SpaceX for commercial crew transportation services that began in FY 2021. CCP is funding milestones on the first Post Certification Missions for each provider. The Crew and Cargo Program is funding the second and all subsequent missions. These crewed vehicles will provide a minimum of 220 pounds of cargo as specified by the ISS program.

NASA purchased crew launches from Roscosmos through October 2020 and crew rescue and return through early April 2021. To ensure continuous U.S. presence aboard the ISS, NASA signed a contract with a U.S. commercial company (Axiom Space of Houston) and flew a NASA astronaut on Soyuz rotation 64S, launched on April 9, 2021. In exchange, NASA will provide a seat on a future U.S. commercial spacecraft, expected to launch in 2023, as part of a space station crew rotation mission.

CREW AND CARGO PROGRAM

Formulation	Development	Operations

Because the services are determined to be of comparable value to both parties, the contract contains no exchange of funds.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Crew transportation	Boeing	Houston, TX
Crew transportation	SpaceX	Hawthorne, CA
Cargo transportation	Northrop Grumman	Dulles, VA
Cargo transportation	Sierra Space	Louisville, CO
Cargo transportation	SpaceX	Hawthorne, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	NASA Advisory Council	Jan 2022	Provides independent guidance for the NASA Administrator	The panel provided no new formal recommendations or findings for the ISS.	Mar 2022
Other	NASA Aerospace Safety Advisory Panel	Jan 2022	Provides independent assessments of safety to the NASA Administrator	The panel provided no new formal recommendations or findings for the ISS.	TBD

COMMERCIAL CREW PROGRAM

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**298.7**	**153.0**	**117.5**	**100.0**	**100.0**	**100.0**	**100.0**
Change from FY 2022 Budget Request			**-35.5**				
Percent change from FY 2022 Budget Request			**-23.2%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

SpaceX Crew-3 astronauts and support personnel participate in water survival training at the Neutral Buoyancy Laboratory at NASA's Johnson Space Center in Houston, Texas (April 30, 2021).

Boeing Starliner technicians work on the Orbital Flight Test-2 spacecraft in the high bay of Boeing's Commercial Crew and Cargo Processing Facility at Kennedy Space Center in Florida (January 13, 2022).

With technical guidance and oversight from NASA, the U.S. private sector is working to develop and operate safe, reliable, and affordable crew transportation to space, including to the International Space Station (ISS). Partnership with the commercial space industry for access to ISS and other low-Earth orbit (LEO) destinations bolsters American leadership, reduces our current reliance on foreign providers for this service, and helps stimulate the American aerospace industry. Crew transportation is currently provided using the newly certified SpaceX Crew Dragon and the Russian Soyuz vehicle. The Boeing Starliner spacecraft is still in the development and test phase but making significant strides towards certification by NASA for crew transportation to ISS. By supporting the development of U.S. human spaceflight capabilities, NASA is also contributing to the foundation of a more affordable and sustainable future for human spaceflight in LEO and beyond.

Through the Commercial Crew Program (CCP), NASA provides technical insight and financial support to industry partners during development of their crew transportation systems using milestone-based contracts and certifies them to carry astronauts to and from the ISS. Under this acquisition model, NASA defines requirements up front and pays the partner only once contract milestones are successfully completed. This approach reduces financial risk to taxpayers and incentivizes the private sector to provide increased cost-control and decreased systems development cost.

The 2014 CCtCap awards represented a significant milestone in U.S. human spaceflight, with the goal of ending our reliance on foreign crew transportation to ISS and certification of safe and cost-effective U.S. commercial crew transportation systems. In addition, this approach helped stimulate growth of new space transportation industry capabilities available to all potential customers, strengthened America's space industrial base, and provided a catalyst for future business ventures that can capitalize on affordable, globally competitive U.S. space access. Returning these launches to American soil has significant economic benefits, with more than 1,000 suppliers working across nearly every state on commercial crew spacecraft systems.

As mentioned in the Crew and Cargo program section, CCP manages the CCtCap contracts. In addition to funding the development and risk mitigation work, CCP also funds each partner's initial Post Certification Mission (PCM). Subsequent PCMs, currently planned for FY 2021 and beyond, are funded by the Crew and Cargo program. A total of nine PCMs have been awarded to SpaceX and six PCMs to Boeing.

In FY 2020, NASA initiated the Suborbital Crew (SubC) activity under the CCP. This activity will develop a system qualification process to enable NASA personnel to leverage suborbital human space transportation capabilities to meet Agency needs and procure commercial suborbital space transportation services for NASA Astronauts and other NASA personnel. After several years of development, commercial suborbital human space transportation systems have become operational. The flight profiles of these vehicles include flying to altitudes of approximately 100 kilometers, which results in periods of microgravity longer than can be created with drop towers and parabolic aircraft flights. Potential uses include human-tended microgravity research, astronaut training, and testing and qualification of spaceflight hardware. Suborbital human spaceflight has the potential to provide an effective and affordable way to meet the Agency's needs and continue efforts to enable a robust spaceflight economy.

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

ACHIEVEMENTS IN FY 2021

In November of 2020, NASA certified that all human rating requirements and crew transportation system requirements were met for SpaceX. Following that certification, the Agency and SpaceX launched Crew-1, the first PCM to the ISS with crew, on November 15, 2020 from Kennedy Space Center's (KSC) Launch Complex 39A in Florida. The Crew Dragon 'Resilience' spacecraft carried astronauts Michael Hopkins, Victor Glover, and Shannon Walker of NASA and Soichi Noguchi of Japan Aerospace Exploration Agency (JAXA) to ISS on that mission. After staying 168 days in orbit, the Crew-1 astronauts returned to Earth in a parachute-assisted splashdown off the coast of Florida on May 2, 2021. On April 23, 2021, just over one week before the Crew-1 departed ISS, SpaceX Crew-2 successfully launched with NASA astronauts Shane Kimbrough and Megan McArthur, along with JAXA's astronaut Akihiko Hoshide and ESA's (European Space Agency) astronaut Thomas Pesquet to begin a six-month science mission on ISS.

COMMERCIAL CREW PROGRAM

The Boeing Orbital Flight Test (OFT)-2 was scheduled for August 3, 2021, but due to an oxidizer isolation valve issue in the Starliner propulsion system, the test flight was delayed. The Boeing team and NASA continues to make progress on the investigation and Boeing has identified a most probable cause related to oxidizer and moisture interactions. Although some verification work remains underway, Boeing began corrective and preventive actions. Additional spacecraft and component testing will be conducted to further explore contributing factors and necessary system remediation before flight.

Suborbital Crew continued progress towards refining the system qualification approach and determining how NASA will qualify commercial suborbital crew systems for NASA personnel.

WORK IN PROGRESS IN FY 2022

CCP will continue to focus on mission planning and preparations for future CCP missions as well as remain actively engaged with the providers as they continue space hardware manufacturing, critical testing, and qualification and verification events.

After staying 199 days in orbit, the Crew-2 astronauts returned to Earth in a parachute-assisted splashdown off the coast of Florida on November 8, 2021. Two days later, on November 10, 2021, SpaceX Crew-3 launched from KSC carrying NASA astronauts Raja Chari, Tom Marshburn, Kayla Barron, and ESA (European Space Agency) astronaut Matthias Maurer. The Crew-3 astronauts will spend approximately six months aboard the space station conducting new and exciting scientific research in areas such as materials science, health technologies, and plant science to prepare for human exploration beyond low-Earth orbit and to benefit life on Earth. Space Crew-4 is planned to launch on April 15, 2022. Crew-4 will carry NASA astronauts Kjell Lindgren, Bob Hines, and Jessica Watkins and ESA astronaut Samantha Cristoforetti. Crew-3 astronauts are set to return to Earth in late April 2022. SpaceX Crew-5 is planned for September 2022. NASA has assigned astronauts Nicole Mann and Josh Cassada to the Crew-5 mission. Additional crew members will be announced later. Mann and Cassada previously were assigned to missions on NASA's Boeing Crew Flight Test and NASA's Boeing Starliner-1 mission, respectively. NASA decided it was important to make these reassignments to allow Boeing time to complete the development of Starliner while continuing plans for astronauts to gain spaceflight experience for the future needs of the Agency's missions.

Boeing will continue the production and outfitting of their spacecraft crew and service modules inside the Commercial Crew and Cargo Processing Facility at KSC. Boeing is planning to complete several significant CCtCap milestones necessary to perform the remaining flight test of their crew transportation systems and certify the Starliner crew transportation vehicle. Planned FY 2022 missions include OFT-2, followed by Boeing's first Crewed Flight Test (CFT). Final NASA certification of the Boeing Starliner crew transportation system will occur after a successful CFT.

Suborbital Crew will continue progress towards refining the system qualification approach and determining how NASA will qualify commercial suborbital crew systems for NASA personnel.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

Boeing plans to launch its first PCM, Starliner-1, to ISS with crew. Once CCtCap development and certification is complete, both partners' space transportation systems will begin regularly flying astronauts to and from ISS. These missions will represent major milestones in the return of human spaceflight from the United States. CCP will transition to sustaining operations at a level needed to safely operate with two commercial providers. CCP will continue to manage the CCtCap contracts, including providing technical oversight and managing modifications and upgrades to the transportation systems.

NASA will begin to leverage commercial suborbital crew systems to fly NASA personnel to perform microgravity research and other testing and qualification for spaceflight hardware, as well as conduct astronaut training.

Program Schedule

NASA funds SpaceX and Boeing crew missions related to United States Orbital Segment (USOS) crew requirements. Commercial crew flights planned for FY 2022 are provided in the table below. However, future crewed flight mission dates are under review (U/R) and not included in the table.

Date	Significant Event
Launch: Nov 2021 Return: Apr 2022	SpX Crew-3
Launch: Apr 2022 Return: Sep 2022	SpX Crew-4
Launch: Fall 2022 Return: TBD 2023	SpX Crew-5
May 2022	Boeing OFT2
TBD 2022	Boeing CFT

Program Management & Commitments

The Space Operations Mission Directorate (SOMD) team at NASA Headquarters performs strategic management and oversight of CCP, while KSC is responsible for day-to-day CCP management, in collaboration with the Johnson Space Center (JSC). CCP partners with industry leaders and is utilizing a combination of Space Act Agreements and Federal Acquisition Regulation (FAR)-based fixed-price contracts to stimulate efforts to develop and demonstrate crew transportation capabilities.

Program Element	Provider
Commercial Crew Program	Providers: Blue Origin (no exchange of funds), Boeing, Sierra Nevada (no exchange of funds), SpaceX Lead Center: KSC Performing Center(s): All Cost Share Partner(s): Industry Partners (shown above)

COMMERCIAL CREW PROGRAM

Acquisition Strategy

CCP facilitates development of a U.S. commercial crew space transportation capability with the goal of achieving safe, reliable, and cost-effective access to and from space and ISS. Under the CCP's partnership approach, NASA engineers have insight into a company's development process and evaluate the systems for overall safety, reliability, and performance. The Agency's technical expertise and resources are also accessible to partner companies. Because companies are only paid a fixed amount, they are incentivized to reduce costs and to apply their most efficient and effective manufacturing and business operating techniques throughout the process. Additionally, the companies own and operate their own spacecraft.

The current and final stage of the acquisition lifecycle began with the award of two FAR-based fixed-price CCtCap contracts in September of 2014 for the development, test, evaluation, and final NASA certification of a Crew Transportation System. CCtCap contracts include demonstration of crewed ISS missions and subsequent service missions, assuming sufficient budget and technical progress. The contracts also include a Special Studies Services section for special studies, tests, or analyses, as needed by NASA to reduce program risk. NASA's FAR based fixed-price contracts during this phase allow for compliance with NASA's existing mission and safety requirements for transporting crew to and from ISS.

NASA measures partner progress against fixed-price milestones, based on performance of agreed upon entrance and success criteria. Although the content varies by partner, milestones are designed to demonstrate progress toward completing crew transportation system development, such as risk reduction testing, design reviews, hardware development, and flight tests. The Government pays for milestones only after completion. Also, the partners will own and operate their completed transportation systems.

Major Contracts/Awards

Element	Vendor	Location (of work performance)
CCDev2 (follow-on)	Blue Origin	Kent, WA
CCtCap	Boeing	Houston, TX
CCiCap (follow-on)	Sierra Nevada	Louisville, CO
CCtCap	SpaceX	Hawthorne, CA

Independent Reviews

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	Aerospace Safety Advisory Panel	Jan 2022	Provide independent assessments of safety to the NASA Administrator	No new formal recommendations or findings	TBD

COMMERCIAL CREW PROGRAM

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	NASA Advisory Council	Jan 2022	Provide independent guidance for the NASA Administrator	No new formal recommendations or findings	Mar 2022
Other	Standing Review Board (SRB)	Nov 2018	Assess funding and schedule reserve requirements, cost effectiveness during development and impacts to future sustaining operations, and efforts required for successful program implementation	While the SRB identified some risks, issues, and concerns, it found that the program has made good progress in the last year proceeding towards the production and test phase of the program	Not currently scheduled

Historical Performance

The tables below represent historical performance through FY 2021, as of September 30, 2021, and only includes funded milestones.

Commercial Orbital Transportation System (COTS) Partner	No. of Mile-stones	Total Potential Value (in $M)	No. Milestones Completed	Funding for Completed Milestones (in $M)	% Milestones Completed	% Funding Completed	Status
SpaceX	40	396.0	40	396	100%	100%	Completed
Orbital	29	288.0	29	288.0	100%	100%	Completed
Rocketplane-Kistler	15	206.8	3	32.1	20%	16%	Terminated

CCDev1 Partner	No. of Mile-stones	Total Potential Value (in $M)	No. Milestones Completed	Funding for Completed Milestones (in $M)	% Milestones Completed	% Funding Completed	Status
Sierra Nevada	4	20	4	20	100%	100%	Completed
Boeing	36	18	36	18	100%	100%	Completed
Blue Origin	7	3.7	7	3.7	100%	100%	Completed
Paragon Space Development Corporation	5	1.4	5	1.4	100%	100%	Completed

COMMERCIAL CREW PROGRAM

CCDev1 Partner	No. of Mile-stones	Total Potential Value (in $M)	No. Milestones Completed	Funding for Completed Milestones (in $M)	% Milestones Completed	% Funding Completed	Status
United Launch Alliance	4	6.7	4	6.7	100%	100%	Completed

CCDev2 Partner	No. of Mile-stones	Total Potential Value (in $M)	No. Milestones Completed	Funding for Completed Milestones (in $M)	% Milestones Completed	% Funding Completed	Status
Sierra Nevada	13	105.6	13	105.6	100%	100%	Completed
Boeing	15	112.9	15	112.9	100%	100%	Completed
SpaceX	10	75	10	75	100%	100%	Completed
Blue Origin	10	22	10	22	100%	100%	Completed

CCiCap Partner	No. of Mile-stones	Total Potential Value (in $M)	No. Milestones Completed	Funding for Completed Milestones (in $M)	% Milestones Completed	% Funding Completed	Status
Sierra Nevada	11	227.5	11	227.5	100%	100%	Completed
Boeing	20	480	20	480	100%	100%	Completed
SpaceX	15	460	15	460	100%	100%	Completed

CCtCap Partner	No. of Mile-stones	Total Potential Value (in $M)*	No. Milestones Completed	Funding for Completed Milestones (in $M)	% Milestones Completed	% Funding Completed	Status
Boeing	50	2,203.3	41	1,823.7	82%	83%	Active
SpaceX	32	1,230.5	32	1,230.5	100%	100%	Active

** Total Potential Value cited is limited to the design, development, test, and evaluation portion of the contracts. Excludes post certification mission, special studies milestones, and milestones not deemed a prerequisite for certification.*

SPACE COMMUNICATIONS AND NAVIGATION

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Space Communications Networks	398.3	393.4	**415.0**	471.5	492.1	465.2	388.0
Space Communications Support	107.7	129.3	**113.4**	103.2	101.6	100.3	105.8
Total Budget	**506.0**	**522.6**	**528.5**	**574.7**	**593.6**	**565.5**	**493.8**
Change from FY 2022 Budget Request			**5.9**				
Percent change from FY 2022 Budget Request			**1.1%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Deep Space Network 34-meter antenna in Canberra, Australia.

NASA's Space Communications and Navigation (SCaN) capabilities provide mission-critical communications and navigation services required by all NASA human and robotic missions. These missions range from high-altitude balloons, to the International Space Station (ISS) in low-Earth orbit (LEO), to Voyager 1, which is the most distant manmade object, currently more than 14 billion miles from Earth. SCaN retrieves science, spacecraft, and crew health data for all these missions, uploads commands, and sends data to individual control centers. Navigation services determine the precise location of a satellite so it can control its trajectory through space, gather valid scientific data, and avoid other spacecraft or space debris.

Without services to move data and commands between spacecraft and Earth, space assets worth tens of billions of dollars would be little more than orbital debris. SCaN provides secure, reliable, and adaptable communication services to NASA missions, as well as external customers who rely on space communications services daily. External customers include foreign governments, international partners, commercial entities (e.g., launch service providers), and non-NASA U.S. missions to which SCaN provides services on a reimbursable basis.

The Near Space Network (NSN) provides communication services to NASA users and missions using a combination of commercially-owned and Government-owned ground assets, along with relay spacecraft which allow for near real-time, low latency support, including support for human spaceflight operations. The relay component is comprised of a constellation of Tracking and Data Relay Satellites (TDRS) and various ground terminals. This allows SCaN to offer 24/7 global telecommunication services via the NSN for telemetry, tracking, and command of LEO spacecraft.

The NSN supports an extensive and diverse customer base from suborbital to Lagrangian orbits by providing direct-to-ground data transfer from spacecraft at S-, X-, and Ka-band frequencies up to data rates of gigabits per second. The NSN supports users that require low latency global coverage through TDRS, by utilizing a mix of ground antennas owned by NASA, universities, and private companies to maximize the network's geographic coverage. Such users include the Hubble Space Telescope and ISS (for which the NSN provides constant communication), as well as vehicles from international partners and commercial interests.

SCaN's goal is to migrate the NSN completely away from Government-owned assets by leveraging the diverse space communications capabilities provided by private industry to provide new technology and capabilities for NASA missions. A key part of this migration includes commercial service demonstrations managed by the Communications Services Program.

While the NSN primarily supports missions close to the Earth, the Deep Space Network (DSN) is focused on supporting deep space missions by utilizing its global network of large antenna ground assets. Both networks will support Commercial Crew providers and Artemis missions. The DSN is a keystone of NASA's exploration of the solar system. It provides reliable and high-performance telecommunications and tracking services to planetary missions. This international network of 34-meter and 70-meter antennas supports interplanetary spacecraft missions and radio and radar astronomy observations for the exploration of the solar system and the broader universe. Current locations of the three deep space communications facilities placed approximately 120 degrees of longitude apart around the world are: at Goldstone, in California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia.

NASA uses the SCaN-provided Goldstone Solar System Radar to track and characterize near-Earth objects that pass within nine million miles of Earth and to determine their orbits for use by the Science Mission Directorate’s (SMD) Planetary Science Division in assessing the probability of a possible collision with Earth. The installation of new radar equipment, planned for completion in FY 2026, will extend the radar's capability to 42 million miles, which increases the time to develop viable solutions to avoid orbital collision for planetary defense.

Both networks require maintenance, replenishment, modernization, and capacity expansion to ensure continued operation and to meet new mission needs. Human and robotic exploration of the Moon requires communications to support video, telemedicine, and advanced instruments that locate and identify exploitable resources on the Moon (e.g., subsurface ice). SCaN is engaged in the planning of the Artemis Campaign's lunar exploration and science missions to ensure that communications and navigation capabilities meet mission needs. SCaN is planning for expanded services for missions to the Moon, including lunar relay capability for missions that cannot communicate directly with Earth and enhanced position, navigation and timing services that are less dependent on tracking stations on Earth. SCaN will seek to maximize the use of commercial assets and services when implementing these new capabilities.

Space Communications Support provides efficient planning and integration of current and future network capabilities to meet customer mission needs while reducing costs. It provides systems engineering, architecture planning, communications data standards, technology development, testbeds for future capabilities, radio frequency spectrum management, and navigation policy.

Operating in space requires significant national and international coordination. SCaN participates in several U.S. and international organizations that coordinate compatibility and interoperability in space communications and navigation. SCaN’s standards development and management activity maintains a portfolio of international interoperability standards that enable joint space missions with other nations.

SPACE COMMUNICATIONS AND NAVIGATION

SCaN also promotes new technologies and provides technical leaders and domain experts who ensure appropriate space communication standards are available to NASA missions. The research and technology avenues within SCaN aim to predict the needs of future communications missions in a manner that will yield initiatives with performance advancements and reduced costs.

Amid soaring demand for wireless broadband, such as 5G mobile services, radio frequency spectrum management has become increasingly critical to the world's spacefaring nations. SCaN coordinates nationally and internationally to protect radio frequencies critical to NASA space and science missions.

For more information, go to http://www.nasa.gov/scan

EXPLANATION OF MAJOR CHANGES IN FY 2023

SCaN is increasing its infrastructure to support human and robotic exploration of the moon, including providing a lunar relay capability and enhanced position, navigation, and timing.

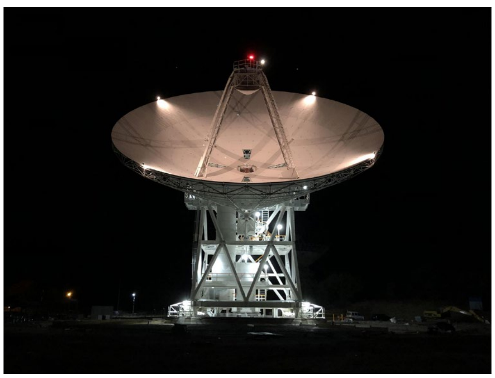
SPACE COMMUNICATIONS NETWORKS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**398.3**	**393.4**	**415.0**	**471.5**	**492.1**	**465.2**	**388.0**
Change from FY 2022 Budget Request			**21.6**				
Percent change from FY 2022 Budget Request			**5.5%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



Deep Space Station 56 (DSS-56) at the Deep Space Network's Deep Space Communications Complex in Madrid, Spain. DSS-56 was brought online at the DSCC in early 2021 after beginning construction in 2017.

Space Communications Networks provide 24/7, global, near-Earth and deep space communications capability, plus tracking and navigation services to more than 100 NASA programs and other U.S. Government, international civil space agencies, and commercial missions. This capability ensures reliable and near-continuous communication with NASA and customer spacecraft. The SCaN program continuously examines and integrates commercial capabilities, and services to meet NASA's space communications and navigation requirement.

NASA's space communications networks provide ongoing services to Agency and customer missions, averaging approximately 600 tracking passes per day. Services are provided to both to new spacecraft that are increasingly powerful, complex, and capable of acquiring an increasing amount of mission data, as well as to legacy missions such as the two Voyager spacecraft launched more than 40 years ago that are still returning valuable science data. Customer missions include Parker Solar Probe (PSP), Joint Polar Satellite System (JPSS), Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight), Ice, Cloud and land Elevation Satellite (ICESat-2), Lucy, Landsat 9, Mars Perseverance, Commercial Crew, and Transiting Exoplanet Survey Satellite (TESS). NASA would not be able to deliver key science data or advance exploration goals without SCaN's network capabilities. The networks will support the Artemis Campaign as the Agency aims toward the goal of landing the first woman and first person of color on the Moon. Human exploration of the Moon requires communications and navigation to and from the Moon to support video, telemedicine, and advanced instruments to locate and identify exploitable resources on the Moon, such as subsurface ice.

The Near Space Network (NSN) will provide near-continuous communication services to users from ground level up to cislunar distances via commercial and government assets. The NSN enables the

SPACE COMMUNICATIONS NETWORKS

utilization of a reliable, robust, and cost-effective set of commercial communications services in which NASA is one of many customers. NSN government assets are maintained and operated by the Advanced Communications Capabilities for Exploration and Science Systems (ACCESS) project NSN is the prime user interface for current and future missions to ensure compatibility, complete pre-mission planning, and provide communication services during mission operations. NSN will act as the Government interface to commercial service providers located in the United States and internationally. The Commercial Services, Innovation, and Synergies (CIS) office aids with the infusion of future commercial capabilities and services into the NSN. A key technology that SCaN is currently developing to support commercialization is wideband tunable user terminals.

As a part of the NSN, NASA's Tracking and Data Relay Satellites (TDRS) are a system of Government-owned, contractor-operated communications satellites in geosynchronous orbit matched with a set of space-to-ground link terminals located at NASA's White Sands Complex in New Mexico, Guam, and Blossom Point, MD. NASA will continue to maintain Government-owned ground stations necessary to communicate with geosynchronous, lunar, and highly elliptical Earth orbits, as well as spacecraft launched from certain suborbital launch locations. The NASA-owned ground stations are currently located at White Sands in New Mexico; U.S. McMurdo Antarctic Station; and Wallops Flight Facility (WFF) in Wallops Island, VA.

The Deep Space Network (DSN), which has been in operation for more than 50 years, provides reliable, high performance, and cost-effective communication and tracking services to approximately 40 NASA and non-NASA missions beyond geosynchronous orbit (i.e., more than 22,000 miles above the Earth's surface). It is a worldwide network of 34-meter and 70-meter antennas that supports interplanetary spacecraft missions and radio and radar astronomy observations for the exploration of the solar system and the universe. The DSN currently consists of three deep-space communications facilities located approximately 120 degrees of longitude apart around the world: at Goldstone in California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia. The site separation ensures that any spacecraft in deep space can always communicate with at least one DSN facility as the Earth rotates and the spacecraft continues to move along its trajectory. Additionally, NASA uses the Goldstone Solar System Radar (GSSR) capability to track and characterize near-Earth objects that pass within nine million miles of Earth. The orbits of the near-Earth objects are determined and utilized by the Science Mission Directorate's (SMD) Planetary Science Division to assess the probability of a conjunction between the object and the Earth. Investments in GSSR, such as installation of a new klystron, are underway to increase its capability to support planetary defense research. In FY 2020, SCaN initiated DSN "Road to Green" activities to determine the long-term maintenance and network health requirements to ensure reliability and meet future Agency needs.

The ongoing DSN Aperture Enhancement Project (DAEP) is modernizing and upgrading the DSN to expand capacity, improve flexibility to support customer missions, and reduce operations and maintenance costs. The project is augmenting the capabilities of the existing 70-meter antennas by completing arrays of four 34-meter Beam Waveguide (BWG) antennas at each of the three DSN facilities: California by 2027, Spain by 2026, and Australia by 2029. The BWG antennas allow for antenna arraying and are less complicated, more flexible, and more cost-effective to maintain than the 70-meter antennas. Antenna arraying combines the signals received by two, three, or four 34-meter antennas to offer performance beyond that of one 34-meter antenna and up to the equivalent of a 70-meter antenna. When

SPACE COMMUNICATIONS NETWORKS

missions do not require all four 34-meter antennas to be arrayed, the 34-meter antennas can support multiple spacecraft individually, offering greater flexibility than a single 70-meter antenna. The new 34-meter antenna construction efforts use Construction of Facilities funds appropriated in NASA's Construction and Environmental Compliance and Restoration account. As part of future DAEP requirements, SCaN plans to install an 80-kilowatt transmitter on one 34-meter BWG antenna per DSN facility to match the transmit capabilities of a 70-meter antenna. Thus, 70-meter antenna capability redundancy will be achieved via arraying of 34-meter BWG antennas for signal receipt and via an 80-kilowatt transmitter on one 34-meter BWG antenna per complex for signal transmission.

NSN and DSN support a different set of customer requirements for spacecraft orbit, signal strength, and real-time coverage. Both networks provide services to customer missions at a proficiency above 99 percent. To continue providing this level of support, each network requires regular maintenance, modernization and capacity expansion, and IT security upgrades to combat the ever-growing cybersecurity threats toward U.S. assets.

SCaN will continue work on an interoperable lunar relay and network. The network is required to meet all of the communication and navigation needs for lunar mission and support mission objectives such as human landing, sustained human presence, and scientific exploration on and around the Moon. The Lunar Exploration Ground System (LEGS), a dedicated new set of 18-meter antennas, will provide additional capacity in support of Lunar Exploration and other missions while preserving DSN capacity for Mars and outer planet missions.

EXPLANATION OF MAJOR CHANGES IN FY 2023

SCaN is increasing its infrastructure to support human and robotic exploration of the moon, including providing a lunar relay capability and enhanced position, navigation, and timing. Development of wideband tunable user terminals is being transferred into SCaN Space Communications Networks from SCaN Space Communications Support as of FY 2022.

ACHIEVEMENTS IN FY 2021

Consistent with prior years' successes, the legacy space communications networks provided approximately 245,000 tracking passes while maintaining a high level of proficiency, greater than 99 percent. A proficiency of 95 percent is required by the SCaN Program Commitment Agreement. SCaN Networks will continue providing communications, tracking, and navigation services to more than 100 NASA, U.S. Government, international civil space agencies, and commercial missions at a 95 percent or higher proficiency rate. This includes providing launch support on human spaceflight, Commercial Launch Vehicle (CLV), and robotic missions. DSN and ACCESS continued to identify and implement more advanced and efficient methodologies and processes, as well as upgraded equipment to achieve improvements over historical operational efficiencies and goals.

SGSS completed Initial Operational Capabilities (IOC) and transition to operations for Main Mission Antenna-1 (MMA-1), the first operational SGSS terminal. After significant impacts from COVID-19 restrictions, external delays, and operational constraints, SGSS project adjusted the contractor minimum success criteria to include IOC with Generation-2 TDRS spacecraft and the SGSS required mission set.

SPACE COMMUNICATIONS NETWORKS

On April 12, 2021, General Dynamics support for IOC testing and operations of SGSS was completed and transitioned to ACCESS on June 30, 2021. In August, the team successfully completed the first ACCESS developed and executed SGSS software delivery. The Minimum IOC, completed in September of 2021, characterized the preliminary capabilities of the SGSS system by supporting a subset of legacy user missions.

NSN continued Ka-band upgrades by installing the WG5 antenna reflector lift and installation at WFF. All four antenna system installations were completed for the NSN Initiative for Ka-band Advancement (NIKA) effort. The NIKA tri-band antennas will support the NASA and Indian Space Research Organization Synthetic Aperture Radar (NISAR) and Plankton Aerosol and Ocean cloud Ecosystem (PACE) satellites, with extremely high-resolution imagery at an estimated 35 terabytes of data downloaded per day.

NSN successfully supported the launch of the SpaceX Inspiration 4 mission in September 2021, a fully commercial crewed mission, and provided communications and tracking support to Inspiration 4 through splash down.

SCaN implemented Delay Tolerant Networking (DTN) operations in support of future missions, including the Artemis Campaign. DTN completed phase one IOC in spring 2021. The phase two cislunar operating capability was successfully completed in summer 2021.

In FY 2021, SCaN completed the DSN "Road to Green" study to determine the long-term maintenance and network health requirements to ensure reliability and meet future Agency needs. The study assessed the current state of the network, evaluated operational risks and budget requirements, and aimed to address the findings and recommendations in the 2020 Office of Inspector General (OIG) report "NASA's Planetary Science Portfolio." SCaN submitted a formal response to the OIG. The DSN Road to Green initiative will execute results from the DSN study.

DAEP successfully delivered Deep Space Station (DSS)-56 to operations at Madrid Deep Space Communications Complex (MDSCC) on January 21, 2021, with a virtual ribbon cutting ceremony held on January 22, 2021. DSS-53 major construction at MDSSC has been completed and the antenna completed integration and testing (I&T) activities in Q1 FY 2022. DSS-53 is scheduled for delivery to operations in Q2 of FY 2022. During Q2 FY 2021, contracts were awarded, and site preparations began for DSS-23 at the Goldstone Deep Space Communications Complex (GDSCC).

In support of the acquisition of Lunar Communications Relay and Navigation Services, SCaN released a Request for Information from potential commercial service vendors in October 2020. Responses were received from 32 companies. In September 2021, SCaN released a Sources Sought Notice for commercial direct-to-Earth (DTE) and lunar relay services in preparation for a planned solicitation for these services. Responses were received from 34 companies. A specification for Lunar Communications and Navigation Interoperability was drafted by SCaN and shared with the commercial and international community.

SCaN and the Communications Services Program are transitioning NASA's future near-Earth missions towards the use of commercial space relay services. SCaN completed a ground-based demonstration of a prototype RF wideband terminal with Inmarsat, O3b, and TDRS services. The terminal will be able to support low-latency space relay links across NASA, commercial, and DoD assets. It will also provide future NASA near-Earth missions capability to roam and utilize commercial relay services.

SPACE COMMUNICATIONS NETWORKS

Interoperability prevents single service provider lock-in and increases the overall robustness and reliability of communication services for end users.

WORK IN PROGRESS IN FY 2022

Consistent with prior years' successes, SCaN Networks will continue to provide communications, tracking, and navigation services to more than 100 NASA, U.S. Government, international civil space agencies, and commercial missions at a 95 percent or higher proficiency rate.

NSN will complete the transition of SGSS to Operations. NSN continues to modernize and upgrade facilities, such as the Second TDRS Ground Terminal (STGT) water system at White Sands Complex with ORR scheduled for March 2022. NSN will also continue development of a conceptual design approach for sustainment activities to improve system reliability and operational efficiency.

NSN will execute an implementation plan to fully commercialize the DTE communications services for LEO customers. NASA will be able to better leverage the evolving capabilities of the private sector while still ensuring reliable support of user communication and navigation requirements through a robust, interoperable, and comprehensive network.

NSN continues progress for Ka-band Advancement (NIKA) effort with level 5 Test Readiness Review (L5 TRR) and Normal Operations Readiness Review (NORR) planned for Q2/Q3 FY 2022 to meet mission launch readiness dates for NISAR and Plankton.

DSN will complete DSS-35 BWG antennas emergency repair work at the Canberra Deep Space Communications Complex (CDSCC) and return the antenna to service. Additional repairs are planned for DSS-26 at the Goldstone Deep Space Communications Complex (GDSCC) for the BWG TXR Servo Obsolescence which will induce a downtime until Q2 of FY 2023. DSN began a DSS-65 downtime maintenance period in late FY 2021 at MDSCC and will return to service in early FY 2022.

DSN will complete installation of a badge reader access control replacement system at the Goldstone Deep Space Communications Complex (GDSCC) in Q2 FY 2022. The badge replacement system will improve physical security at the main gate and Venus, Apollo, and Mars sites. The new system will bring GDSCC security at the designated sites into compliance with Enterprise Physical Access Control system (EPACS).

At MDSCC, DAEP will successfully deliver DSS-53 to operations in Q2. DSS-23 radio frequency (RF) optical pedestal construction and antenna erection will begin, and the facilities contract will be awarded in FY 2022. DSS-54 facilities contract will also be awarded in Q3/4 of FY 2022. DSS-13 7-segment testing to be completed at JPL and ready to ship to DSS-13 facilities at GDSCC by Q2/Q3 of FY 2022.

The DSN and NSN will continue network upgrades in support of lunar missions as human and robotic exploration of the Moon will require extensive communications to and from the Moon including support for video, telemedicine, and advanced instruments. The DSN Lunar Exploration Upgrades (DLEU) effort provides capability upgrades to the DSN 34-meter subnet to support enhanced communications requirements for Artemis. Specifically, two antennas per complex will have K-band (22.5 GHz) uplinks and will support 20 Mbps data rates. Downlink processing will be upgraded through the use of improved decoding for error-correcting code and a low latency processing capacity of 150 Mbps. These new capabilities will allow real-time video from the Moon. In FY 2022 near-Earth K-band installation will be completed for one 34-meter antenna in Canberra and one 34-meter antenna in Madrid. The DLEU task started compatibility testing with Gateway in early FY 2022.

In April 2021, preliminary requirements were defined at the LEGS System Requirements Review (SRR) Tabletop, and pre-Phase A tri-band antenna technical interchange meetings were conducted with potential vendors. The Preliminary Design Review (PDR) project milestone for LEGS is scheduled for Q4 FY 2022 which will serve as a technical assessment on the baseline system operational functionality.

SCaN completed an Agency-level Acquisition Strategy Meeting (ASM) in November 2021 for Lunar relay capabilities. NASA plans to release a DTE and Lunar Relay Services Request for Proposals (RFP) in the second quarter of FY 2022 with awards planned for the summer of 2022. In parallel, SCaN will continue collaboration with the European Space Agency and other potential international partners to pursue cooperative efforts toward lunar communications and navigation capabilities. SCaN has prepared a draft document to define interoperability standards for a cooperative lunar network and is working with international partners and private companies to reach a consensus on a baseline standards document. SCaN also completed a reference design for a lunar relay satellite concept as background for the commercial service procurement and international collaboration.

After completing successful ground-based demonstrations of a wideband multilingual RF terminal in FY 2021, SCaN will initiate work on a flight demonstration to prove that interoperable SATCOM services are an achievable end and operational concept for future NASA users. The Wideband flight terminal demonstration will initiate work and complete a CDR in FY 2022.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

SCaN Networks will continue to provide communications, tracking, and navigation services to more than 100 NASA, U.S. Government, international civil space agencies, and commercial missions at a 95 percent or higher proficiency rate.

Site preparation will begin for DSS-33 at the CDSCC. Facilities installations and the reflector lift will be completed for DSS-23 at MDSCC. The DSS-23 upgrades will support the Psyche/DSOC mission and other optical communication demonstration opportunities. DLEU upgrades will also continue with two more antennas completing the K-band installation.

DSS-54 site excavation at MDSCC is scheduled to be completed in Q3 FY 2023 in support of the DAEP DSS-54 pedestal rehab plan. Excavation completion by Q3 FY 2023 will facilitate antenna operational readiness by Q4 2026.

Scheduled completion of an upgraded fencing system at the Apollo GDSCC site is planned for Q3 FY 2023. The fencing upgrade will significantly improve security measures at the GDSCC location and will complement additional security improvements planned on site in the FY 2022, including EPACS compliant badging system upgrade.

LEGS will provide a dedicated new set of antennas designed to support lunar missions, to help alleviate the user load on the current 34-meter subnet, to allow DSN to focus on deep space support. A decision to incorporate tri-band antennas into LEGS sites 2 and 3 will be made based on study results. SCaN will also continue work on an interoperable lunar relay and network. The awards in summer 2022 will define the detailed milestones planned for FY 2023 including the beginning of validation for commercial lunar relay services.

The Operational Readiness Review (ORR) for the Orion Artemis-II Optical Ground Segment (O2OGS) at the White Sands Complex is scheduled for Q4 FY 2023. The ORR is one of the final milestones for O2OGS and successful completion of the ORR will determine that O2OGS is ready to be placed in an operational status. This ensures that all system and support hardware, software, personnel, procedures, and user documentation accurately reflect the deployed state of the system and are in place to support launch operations of Artemis II.

The Laser Communications Relay Demonstration (LCRD) is scheduled to complete its experimental phase in Q2 FY 2023. The experimental phase will demonstrate unique capabilities of optical communications, which include bandwidth increases of 10 to 100 times more than radio frequency systems. After the experimental phase is completed, LCRD will transition to NSN for operations.

SCaN's Wideband demonstration will complete selection of a commercial satellite smallsat bus provider and operator, a terminal integration review, and initiate final integration and testing in FY 2023.

Project Schedule

The table below includes significant SCaN network milestones in FY 2022 and FY 2023.

Date	Significant Event
Q1 FY 2022	DLEU Compatibility Testing with Gateway
Q1 FY 2022	DAEP 7-Segment Testing at JPL
Q2 FY 2022	DSN GDSCC Badge System Upgrade
Q2 FY 2022	DAEP DSS-53 Operational
Q2 FY 2022	NSN NIKA Level 5 Test Readiness Review (TRR)
Q2 FY 2022	NSN Lunar Relay Services and DTE RFP
Q3 FY 2022	NIKA NORR
Q3 FY 2022	LEGS Preliminary Design Review (PDR)
Q3 FY 2022	DAEP DSS-54 Facilities Contract Award
Q4 FY 2022	DSN BWG Servo Obsolescence 1st Installation DSS-26 Begins
Q1 FY 2023	DSN GDSCC Apollo Fence Completion
Q2 FY 2023	LCRD Begins Transition to NSN
Q3 FY 2023	DAEP DSS-54 Excavation Completion
Q4 FY 2023	Orion Artemis-II Optical Ground Segment (O2OGS) Operational Readiness Review (ORR)

SPACE COMMUNICATIONS NETWORKS

Project Management & Commitments

Element	Description	Provider Details	Change from Formulation Agreement
ACCESS	ACCESS provides the project management and subject matter expertise required to operate, maintain, and sustain assigned Government Owned / Contractor Operated ground- and flight-based systems and assigned facilities in order to provide NASA, other Government agencies, and partners optimal communications and navigation mission services through its alignment to and interfaces with the NSN.	Provider: ACCESS Project Office Lead Center: Goddard Space Flight Center (GSFC) Performing Center(s): N/A Cost Share Partner(s): Non-NASA customers	N/A
NSN	NSN provides the project management and subject matter expertise required to provide continuous LEO communication services to users via commercial and Government assets and providers. NSN will act as the Government interface to the commercial service providers located in the U.S. and internationally.	Provider: NSN Project Office Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): Non-NASA customers	N/A
CIS	CIS functionally will provide project management leadership and subject matter expertise required to identify opportunities, extend invitations, implement collaborative solutions, and nurture diverse relationships in order to leverage commercial capabilities across the space communications industry.	Provider: CIS Project Office Lead Center: GSFC Performing Center: N/A Cost Sharing Partner(s): Non-NASA customers	N/A
DSN	DSN provides communication and navigation services to customer missions in deep space.	Provider: DSN Project Office Lead Center: Jet Propulsion Laboratory (JPL) Performing Center(s): N/A Cost Share Partner(s): Non-NASA customers	N/A

SPACE COMMUNICATIONS NETWORKS

Element	Description	Provider Details	Change from Formulation Agreement
SGSS	Replace outdated and deteriorating ground systems at Space Network ground terminals.	Provider: SGSS Project Office Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): Non-NASA U.S. Government partners	N/A

Acquisition Strategy

The major acquisitions for the operational networks are in place. NASA uses reimbursable, international, and barter agreements, as well as competitive procurements. NASA's JPL provides the management of the DSN. The Communications Services Program (CSP) is conducting pilot efforts for commercial communications services for NASA's near-Earth missions. If these pilots are completed successfully, subsequent operational services would be transitioned from CSP to SCaN. SCaN is also preparing a solicitation for Lunar communication and navigation services in direct support of Artemis.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
DSN	JPL/California Institute of Technology	Pasadena, CA
NSN	Peraton	Herndon, VA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
SCaN	Standing Review Board	FY 2021	Program Implementation Review with focus on interdependencies, implementation planning, and risk gaps or shortfalls.	Success criteria met; major strengths, observations, concerns, and issues were identified	FY 2026

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**107.7**	**129.3**	**113.4**	**103.2**	**101.6**	**100.3**	**105.8**
Change from FY 2022 Budget Request			**-15.9**				
Percent change from FY 2022 Budget Request			**-12.3%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The Laser Communications Relay Demonstration payload, shown here in the clean room at GSFC, was hosted and flown on a U.S. Space Force technology satellite in December 2021. LCRD will be communicating with two dedicated optical ground stations in California and Hawaii and eventually with a test payload on ISS.

The Space Communications Support project supports NASA and the Space Communications and Navigation (SCaN) program through communications and navigation planning, management, and technology development.

Evolving space communication systems will transform future NASA mission capabilities. SCaN's technology development effort invests in leading-edge communications technologies that will enable, improve, and mature available spacecraft communication and navigation technologies for both ground and space-based use. Technology items are created and tested in laboratory settings before they are taken into space for further testing. Demonstrable technologies have proven themselves in laboratory tests and have begun experimentation and testing in space. Key technologies that SCaN is currently developing include cognitive networking and software-defined radios for use with commercial satellite communication (SATCOM) providers. These technologies will demonstrate use of a common radio to provide cross-service support for NASA, commercial, and Department of Defense (DoD) networks.

Another key space communications technology is optical (i.e., near-infrared laser) communications. Laser communication is highly efficient compared to radio frequency. Transmitting a 30-centimeter resolution map of the entire Martian surface (at one bit/pixel) would take current radiofrequency (RF) systems two years, while a laser communications system operating at projected capacity would be able to complete transmission in nine weeks, a nearly 12 times reduction in task time. NASA's Space Technology Mission Directorate (STMD) and SCaN jointly developed the Laser Communications Relay Demonstration

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

(LCRD), with SCaN funding the ground operations and STMD funding the spacecraft payload. LCRD will be NASA's first long duration optical communications project and will demonstrate a set of technologies that could be used on future missions. Other LEO optical technology demonstrations include: an optical user terminal called the Integrated LCRD Low-Earth Orbit User Modem and Amplifier Terminal (ILLUMA-T), that will fly on ISS and communicate to the LCRD relay, demonstrating a 1.244 gigabits per second relay link in 2023; Optical-to-Orion (O2O), a terminal on the Orion spacecraft that will provide 260 megabits per second of bandwidth, a rate not available with the current Orion communications system; and the TeraByte InfraRed Delivery (TBIRD), a CubeSat payload capable of delivering 200 gigabits per second from LEO to Earth. The TBIRD payload technology is based on 1550 nanometer wavelength commercial components used for terrestrial fiberoptic connections.

Deep Space Optical Communications (DSOC) is another critical technology being developed through a joint SCaN/STMD collaboration. DSOC will conduct optical communications from deep space, demonstrating key capabilities related to pointing accuracy and implementation of the High Photon Efficiency signaling standard. SCaN sponsors the ground network, including the five-kilowatt uplink beacon at the JPL Table Mountain facility and a superconducting single-photon-sensitive nanowire detector and real-time receiver at the Palomar Observatory in California. DSOC is currently on track to be integrated onto the Psyche planetary science mission, scheduled to launch in FY 2022.

SCaN continues to invest in the Deep Space Atomic Clock (DSAC) technology to mature designs for future mission use. DSAC technology allows a spacecraft to calculate its own timing and navigation data in real-time. With existing technology, a spacecraft can navigate autonomously to the top of the Martian atmosphere with uncertainty of one to two kilometers. It is expected that DSAC will enhance deep space navigation and reduce positional uncertainty to 100 meters, an improvement factor of 10 to 20 over today's capabilities, which will save fuel and enable more accurate scientific measurements. DSAC's improved long-term stability will also enhance on-board, autonomous navigation for future robotic and crewed missions, and enable investigations of fundamental physics (e.g., relativity). Further, DSAC's long-term stability will reduce network operations costs for tracking data collection by enabling one-way metric tracking. This allows a single antenna to service multiple DSAC-using spacecraft at common locations in the sky (e.g., Mars).

SCaN is researching opportunities to leverage investments, experience, and accomplishments from optical communications to build foundational capabilities needed for future spaced-based quantum communications and networking.

SCaN is an active member of multiple international organizations (e.g., Interagency Operations Advisory Group [IOAG], Consultative Committee for Space Data Systems [CCSDS]) that coordinate space communications and navigation compatibility and interoperability, as well as the development of communications and data systems standards for spaceflight. Space communications data standards enable the world space agencies and industry to interoperate and provide communications and/or backup communications services with each other, reducing mission risk and reducing or eliminating the need to build and deploy their own space and ground assets. These standards provide significant cost savings to NASA without reducing services or coverage to space missions and serve as a compatibility and interoperability guide for industry.

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

Electromagnetic spectrum is a valuable and limited natural resource that all NASA missions and most operations require for communications, navigation, remote sensing, and data services in the areas of Earth science, space science, human space exploration, and aeronautical research. All forms of wireless communication systems used by the Federal Government or by commercial entities use the electromagnetic spectrum. Therefore, spectrum use must be carefully coordinated. SCaN is responsible for ensuring access to the portions of the electromagnetic spectrum necessary to support NASA's mission needs. This responsibility includes ensuring interference-free operations and bandwidth availability. SCaN serves as the Agency's Spectrum Manager and provides NASA representatives to advocate for NASA's requirements at domestic spectrum governing bodies, including the Interdepartment Radio Advisory Committee (IRAC) at the National Telecommunications and Information Administration (NTIA) within the Department of Commerce. Internationally, SCaN participates as NASA's representative at multiple technical forums, the most important of which are the World Radiocommunication Conferences (WRCs), which convene every three to four years and include delegates from more than 150 nations. NASA's delegates play leading roles in several key WRC working groups and regional committees throughout the year. Among the purposes of these conferences is to review and revise the International Telecommunication Union's Radio Regulations, which govern the international use of the electromagnetic spectrum. In both the domestic and international arenas, NASA continues to engage with the commercial sector to identify more flexibility in the use of spectrum resources that will meet mission objectives for the entire space community.

NASA spacecraft in Earth orbit can employ the U.S. Global Positioning System (GPS) and other Global Navigation Satellite System (GNSS) signals for precision positioning, navigation, and timing (PNT), allowing NASA to minimize the network tracking burdens while maximizing spacecraft autonomy and improving operations. In 2019, the NASA Magnetospheric Multiscale (MMS) mission validated the use of GPS signals up to half the distance from Earth to the Moon, and SCaN is now leading NASA efforts on the Lunar GNSS Receiver Flight Experiment (LuGRE) on Blue Ghost-1 (Commercial Lunar Payload Services Mission 19D), scheduled for launch in 2023, to validate the use of GPS and Galileo throughout cislunar space and on the nearside of the Moon. SCaN is collaborating with SMD to furnish a Laser Retro-Reflector to the ESA (European Space Agency) Lunar Pathfinder orbiter, for launch in 2024, to enable combined GPS-Galileo and optical laser measurements to tie the Earth and Moon reference frames and improve navigation in Lunar Space. SCaN is also leading efforts to validate multi-GNSS use to support range safety, including the Space Loft 15 integrated GNSS - Autonomous Flight Termination System (AFTS) flight experiment scheduled for launch in April 2022. SCaN also manages NASA’s policy on GPS use, represents NASA at the U.S. PNT Executive Committee, works with the U.S. Space Force to continue improving GPS capabilities to support space users, and leads U.S. efforts at the United Nations International Committee on GNSS (ICG) to develop interoperable multi-GNSS capabilities to support space users. Another key role is working with other U.S. departments and agencies in mitigating threats to the GPS spectrum, and protecting GPS users from data-spoofing (GPS cybersecurity). SCaN manages two National Advisory Boards, the National Space-Based PNT Advisory Board and the National Space Council (NSpC) Users' Advisory Group (UAG). SCaN continues in its role, first established in 2007 as providing the Designated Federal Official (DFO) and Executive Director of the National Space-Based PNT Advisory Board, which reports to the National Space-Based PNT Executive Committee (EXCOM), which in turn is co-chaired by the Deputy Secretaries of Defense and Transportation. Since 2019, SCaN

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

has provided the DFO and Executive Secretary of the NSpC UAG. The UAG reports to the Executive Secretary of the NSpC. The NSpC itself is chaired by the Vice President of the United States.

EXPLANATION OF MAJOR CHANGES IN FY 2023

The development of wideband tunable user terminals is being transferred from SCaN Space Communications Support to SCaN Networks.

ACHIEVEMENTS IN FY 2021

LCRD Operational Readiness Review (ORR) was completed in May 2021. The LCRD Optical Ground Station (LOGS), which supports high-bandwidth bi-directional GEO-ground optical completed testing and development and became operational in FY 2021. NASA's LCRD launched December 7, 2021.

ILLUMA-T will demonstrate optical communications operations of a user terminal on ISS and Earth using LCRD as the relay. All component hardware was delivered by Q2 FY 2021. Integration and testing of the electro-optical components on the Flight Sled structure began Q3 FY 2021 at Massachusetts Institute of Technology Lincoln Laboratory (MIT-LL). The integrated terminal is scheduled for delivery in Q1 FY 2022 to Goddard Space Flight Center (GSFC) for final environmental testing prior to shipment to KSC in Q3 FY 2022.

The Modem Module for O2O completed thermal vacuum testing in May 2021 prior to delivery to MIT-LL. O2O successfully completed both a pre-environmental review in August 2021 and payload assembly in November 2021.

TBIRD will demonstrate a new approach for large volume data delivery of 5-10 terabytes per day from LEO to a single low-cost optical ground station. TBIRD will enable an optical communications capability that is more compact and less expensive than existing optical communications technologies. TBIRD completed payload integration and testing in August 2021.

SCaN began the integration and test of the DSOC Ground Laser Transmitter and Ground Laser Receiver. SCaN continues efforts to mature DSAC technologies and improve hardware designs.

SCaN completed preliminary assessment of the Technology Readiness Level (TRL) and risk levels of space and ground-based technologies and continued to mature key quantum technologies.

Through participation in the IOAG and CCSDS, SCaN will continue international coordination of space communication and navigation compatibility and interoperability, as well as the development of internationally interoperable space communication and data system standards. NASA missions use internationally interoperable standards to lower the life cycle costs and risks and provide innovative capabilities for current and future missions. Key progress is planned for optical and space internetworking standards. The IOAG will coordinate with other parts of NASA, industry, and international partners on space communications and navigation requirements.

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

SCaN represented NASA at the 15th session of the International Committee on Global Navigation Satellite Systems (ICG). NASA co-chairs the WG-B Space Use SubGroup (SUSG), which presented two formal deliverables: the second edition of the GNSS Space Service Volume (SSV) booklet (update including the latest constellation data from all providers and adding real-world GNSS space user flight experiences), and a companion SSV outreach video. Both deliverables were developed to convey the significant improvements afforded by use of a multi-GNSS SSV and benefits it can provide.

WORK IN PROGRESS IN FY 2022

In November 2021, LCRD passed Key Decision Point (KDP)-E. SCaN will begin LCRD payload operations and management of experiments, including an experiment to verify collection of metric tracking data from optical links (termed Optimetrics) during the two-year experiment period. SCaN will operate and maintain the LCRD payload through the LCRD Mission Operations Center (LMOC) through the prime demonstration operations period of two years post launch.

The O2O payload was completed in November 2021 and integration into the spacecraft will begin no earlier than July 2022. In addition, SCaN has been developing a Ground Terminal (GT) as an element of the O2O Artemis II to prepare for operations at the Optical Communication Telescope Laboratory at the Table Mountain Observatory, which is scheduled to complete integration and testing in Q1 of FY 2023. The GT will support the Orion space terminal with a minimum downlink data rate of approximately 80 megabits per second and an uplink data rate of approximately 20 megabits per second.

TBIRD launch is currently scheduled for FY 2022. This will demonstrate a low-cost burst data delivery architecture and protocols, leveraging high-rate commercial off the shelf telecom equipment for 200 gigabits per second data delivery in a CubeSat form-factor. TBIRD will demonstrate optical high data-rate capabilities designed for small payloads, i.e., a 200 gigabits per second package that is ≤3U, that require reduced size, weight, and power (SWaP).

NASA will complete the DSOC ORR prior to Psyche's launch, which is currently scheduled for late FY 2022.

DSAC follow-on technology maturation will leverage progress of the TRL-7 DSAC technology demonstration mission and data collected from its second year of flight operation to design a commercially manufacturable version of the clock in a reduced SWaP form-factor suitable for a wide-range of space missions. SCaN will continue quantum entanglement pre-formulation and technology maturation focused on ground-based research and development.

NASA will leverage the Navigator weak-signal tracking GPS receiver technology to develop a small form-factor, multi-GNSS receiver (e.g., GPS/Galileo) for use in cislunar and lunar space and complete TRL-6 testing in FY 2022. This will provide reliable, real-time, autonomous, onboard navigation and timing for cislunar and lunar users by leveraging the always-on GNSS assets in orbit around the Earth. This receiver will reduce the tracking burden on Earth-based networks, which are a finite resource, for cislunar and lunar users, and serve as a significant risk reduction for commercial user operations. SCaN is

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

also leading NASA's effort, in partnership with the Italian Space Agency and the ESA to conduct flight experiments of combined GPS-Galileo receivers at lunar distance.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

NASA will launch the ILLUMA-T optical demonstration payload to ISS in FY 2023. This will demonstrate data transfer between low-Earth orbit and the ground through a geosynchronous relay (LCRD). SCaN will continue LCRD payload operations and management of experiments through FY 2023 and into FY 2024.

The O2O payload is scheduled to complete all Ground Readiness Tests (GRTs) and Mission Readiness Tests (MRTs) by the end of Q1 FY 2023. The payload will launch aboard the Artemis II mission in FY 2024. The O2O Ground Terminal at Table Mountain will hold its Operational Readiness Review in Q1 FY 2023 and will be ready to support the Artemis II launch in 2024.

DSOC will enter its Phase E in FY 2023 and complete operations for technology demonstration.

The Blue Ghost-1 lunar lander, which carries the LuGRE GPS-Galileo flight experiment as one of its ten payloads, is scheduled for launch in FY 2023. This experiment will validate the use of GPS and Galileo signals for positioning, navigation, and timing, at lunar distance.

Project Schedule

The table below includes significant Space Communication Support milestones in FY 2022 and FY 2023.

Date	Significant Event
FY 2022	TBIRD Launch
Q1 FY 2022	LCRD Launch
Q3 FY 2022	Space Loft 15 Launch (sounding rocket with GNSS-AFTS flight experiment)
Q3 FY 2022	ILLUMA-T Testing and Integration Complete
Q3 FY 2022	DSOC ORR
Q4 FY 2022	O2O Delivery to KSC
Q2 FY 2023	ILLUMA-T Launch
Q3 FY 2023	Blue Ghost-1 (CLPS Mission 19D) Launch (w/ LuGRE payload)

SPACE COMMUNICATIONS SUPPORT

Formulation	Development	Operations

Project Management & Commitments

The SCaN program office at NASA Headquarters manages Space Communications Support functions.

Element	Description	Provider Details	Change from Formulation Agreement
Space Communications Support	Provides critical communication and navigation architecture planning, systems engineering, technology development, standards development and management, spectrum management, and policy and strategic communications for NASA.	Provider: NASA Responsible Center: Headquarters (HQ)	N/A

Acquisition Strategy

Space Communications Support functions use multiple small, contracted efforts, most of which are support services functions.

MAJOR CONTRACTS/AWARDS

None.

HUMAN SPACE FLIGHT OPERATIONS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**97.8**	**101.8**	**101.5**	**103.7**	**104.3**	**104.3**	**104.3**
Change from FY 2022 Budget Request			**-0.3**				
Percent change from FY 2022 Budget Request			**-0.3%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The Artemis IV Orion heat shield skin is offloaded from the Aero Spacelines Super Guppy to the K Loader at Moffett Federal Airfield on November 9, 2021

The Human Space Flight Operations (HSFO) Program supports the astronaut corps, space flight readiness training, and health of crew members before, during, and after each spaceflight mission to the International Space Station (ISS). All crews on board ISS have undergone rigorous preparation, which is critical to mission success. Within the HSFO program, the Space Flight Crew Operations (SFCO) element provides astronaut selection and space flight readiness training and the Crew Health and Safety (CHS) element manages all aspects of astronaut crew health.

To pave the way to the Moon and on to Mars, NASA is working with industry to develop the transportation, habitation, and exploration systems that will enable crewed exploration of destinations beyond Earth’s orbit. NASA must also prepare the human system for living and working for extended periods in the hostile environment of space. As astronauts explore further from Earth, many different issues will arise and need investigating.

- What health risks will astronauts face and how are they resolved?
- What type of training will crews need to prepare for months of travel in the harsh space environment?
- How will they deal with medical emergencies or technical anomalies when Earth is no longer within reach?

CHS, in collaboration with NASA’s Office of Chief Health and Medical Officer (OCHMO) and the Human Research Program (HRP), answers these and other questions to ensure crew health, safety, and mission success. SFCO and CHS are responsible for astronaut space flight readiness training and health, while HRP funds research of human health and performance countermeasures, the human response to space, and technologies that enable safe, reliable, and productive human space exploration.

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

HUMAN SPACE FLIGHT OPERATIONS

ACHIEVEMENTS IN FY 2021

SFCO provided trained astronauts for NASA human space flight efforts, including for Expeditions 64 and 65. The selection process for the 2021 Astronaut Candidate (ASCAN) class completed with formal announcement in December 2021 of 10 ASCANs. SFCO reviewed crew training requirements for Artemis missions to identify efficiencies and ways to acquire the needed operational and decision - making skills in a real-time environment.

SFCO continued to operate and maintain the T-38 high-performance jets for crew space flight readiness training; Gulfstream aircraft for support of direct crew return after completion of ISS Expeditions as well as mission critical training events due to COVID commercial flying restrictions. Operated and maintained the Super Guppy aircraft transporting oversized cargo for Artemis III and IV Heat Shields and SLS Structural Test Article (Multi-Purpose Crew Vehicle Stage Adapter), and other NASA programs.

CHS maintained the Astronaut Occupational Health Program that includes clinical certification for 45 active NASA astronauts and health and fitness through training, flight, and post mission recovery. CHS implemented the TREAT (To Research, Evaluate, Assess, and Treat) Astronauts Act including enhanced behavioral health and medical data collection, and instituted the TREAT Astronauts Act Board, which assists in determining whether medical conditions are associated with spaceflight. CHS continued development of the occupational surveillance program for current and former astronauts, ensuring the unique Artemis Campaign spaceflight exposures are considered and will be accounted for in future surveillance programs.

To support ISS mission increments, CHS provided preflight training, medical and behavioral health management, physical conditioning, radiation exposure reports, and baseline occupational surveillance, as well as supported medical risk modeling through Probabilistic Risk Assessment tools. For NASA's Artemis, Gateway, and Lunar mission architecture and vehicles, CHS provided analysis and technical expertise to requirements and operational concept development. CHS also medically monitored and supported astronaut training activities for ISS EVAs and Exploration Extravehicular Mobility Unit (xEMU) development. CHS also provided medical and behavioral screening expertise to SFCO in support of the 2022 ASCAN selection.

Data obtained under the TREAT Astronauts Act, as well as all CHS activities, was added into the Information Management Platform for Data Analytics and Aggregation (IMPALA) data analysis tool for informing current and future operational programs and paradigms for crew health, safety and performance. IMPALA continued to improve NASA's access to astronaut medical data to inform programmatic decisions, and CHS delivered the IMPALA Data Catalog to enhance NASA's understanding of the data available within IMPALA. CHS delivered 7 IMPALA data systems required for the evaluation of human system risks to enable lunar and Mars missions. Due to the pandemic, CHS realized the need for in-house COVID testing and obtained an in-house testing capability for SARS-CoV-2 (COVID-19).

WORK IN PROGRESS IN FY 2022

SFCO will direct and manage the astronaut corps and provide trained astronauts for NASA human space flight efforts, including for Expeditions 66 and 67 and the first test flight of the Boeing Starliner on the Crewed Flight Test (CFT) mission. 2021 ASCAN class will report for training to begin a two-year training flow. In addition, SFCO will assign astronauts to be the Artemis II crew and they will begin training for the mission.

HUMAN SPACE FLIGHT OPERATIONS

SFCO will continue to operate and maintain the T-38 high-performance jets in support of space flight readiness training, Gulfstream aircraft for support of direct crew return after completion of ISS Expeditions and CFT, and Super Guppy aircraft for transporting oversized cargo for NASA's programs. SFCO will complete the process for Super Guppy replacement aircraft.

CHS will maintain the Astronaut Occupational Health program that includes clinical certification for 55 active astronauts and health and fitness through training, flight, and post mission recovery. CHS will continue to implement all aspects of the TREAT (To Research, Evaluate, Assess, and Treat) Astronauts Act including enhanced behavioral health and medical data collection, and support the TREAT Astronauts Act Board, which assists in determining whether medical conditions are associated with spaceflight. CHS will continue development of the occupational surveillance program for current and former astronauts, ensuring the unique Artemis Campaign spaceflight exposures are considered and accounted for in the future surveillance program.

To support ISS mission increments, CHS will provide preflight training, medical and behavioral health management, physical conditioning, radiation exposure reports and baseline occupational surveillance, and support medical risk modeling through Probabilistic Risk Assessment tools. For NASA's Artemis, Gateway, and Lunar mission architecture and vehicles, CHS continues to provide analysis and technical expertise to requirements and operational concept development. CHS will medically monitor and support astronaut training activities for ISS EVAs and Exploration Extravehicular Mobility Unit (xEMU) development. CHS will provide the recently selected ASCANs training in fundamentals of expeditionary skills and competencies and individual coaching on the development of these competencies over the course of their training.

Data obtained under the TREAT Astronauts Act, as well as all CHS activities, will continue to be added into the Information Management Platform for Data Analytics and Aggregation (IMPALA) data analysis tool for informing current and future operational programs and paradigms for crew health, safety, and performance. IMPALA will continue to improve NASA's access to astronaut medical data to inform programmatic decisions, and CHS will maintain and update the IMPALA Data Catalog to enhance the community's understanding of the data available within IMPALA. CHS will develop additional IMPALA data systems required for the evaluation of human system risks to enable lunar and Mars missions. CHS will continue to maintain and provide an in-house testing capability for SARS-CoV-2 (COVID-19) and restart the Lifetime Surveillance of Astronaut Health (LSAH) exams which were suspended due to the pandemic.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

SFCO will direct and manage the astronaut corps and provide trained astronauts for NASA human space flight efforts, including for Expedition 68 and 69. SFCO is targeting to select and begin new astronaut training for the 2023 ASCAN class.

SFCO will continue to operate and maintain the T-38 high performance jets in support of space flight readiness training, Gulfstream aircraft for support of direct crew return after completion of ISS Expeditions, and transportation of oversized cargo with the Super Guppy replacement aircraft for NASA's programs.

CHS will maintain the Astronaut Occupational Health program that includes clinical certification for 55 active astronauts and health and fitness through training, flight, and post mission recovery. CHS will continue to implement all aspects of the TREAT (To Research, Evaluate, Assess, and Treat) Astronauts Act including enhanced behavioral health and medical data collection, and support the TREAT

Astronauts Act Board. CHS will finalize the occupational surveillance program for current and former astronauts, ensuring the unique Artemis Campaign spaceflight exposures are accounted for in the future surveillance program.

To support ISS mission increments, CHS will provide preflight training, medical and behavioral health management, physical conditioning, radiation exposure reports and baseline occupational surveillance, and support medical risk modeling through Probabilistic Risk Assessment tools. For NASA's Artemis, Gateway, and Lunar mission architecture and vehicles, CHS will provide analysis and technical expertise to requirements and operational concept development and support these programs with Probabilistic Risk Assessment tools designed for exploration objectives. CHS will medically monitor and support astronaut training activities for ISS EVAs and Exploration Extravehicular Mobility Unit (xEMU) development, and training for up to 2 NASA astronauts for lunar surface EVAs. CHS will continue to provide ASCANs (selected in FY 2022) training in fundamentals of expeditionary skills and competencies and individual coaching on the development of these competencies over the course of their training. CHS will also provide medical and behavioral screening expertise to SFCO in support of the 2024 Astronaut Candidate selection.

Data obtained under the TREAT Astronauts Act as well as all CHS activities, will continue to be added into the Information Management Platform for Data Analytics and Aggregation (IMPALA) data analysis tool for informing current and future operational programs and paradigms for crew health, safety and performance. IMPALA will continue to improve NASA's access to astronaut medical data to inform programmatic decisions, and CHS will maintain and update the IMPALA Data Catalog to enhance the community's understanding of the data available within IMPALA. CHS will develop additional IMPALA data systems required for the evaluation of human system risks to enable lunar and Mars missions. CHS will begin transition to operations of IMPACT (Informing Mission Planning via Analysis of Complex Tradespaces) to support medical risk modeling through Probabilistic Risk Assessment for exploration missions and programs. Pending the future state of the pandemic, CHS will continue to maintain and provide an in-house testing capability for SARS-CoV-2 (COVID-19) and continue the Lifetime Surveillance of Astronaut Health (LSAH) exams with the goal of obtaining a 75 percent participation rate.

Program Elements

SPACE FLIGHT CREW OPERATIONS (SFCO)

SFCO directs and manages the astronaut corps activities, assigns flight crew, is responsible for human space flight readiness training, and maintains and operates the Johnson Space Center (JSC) aircraft fleet, including the T-38 high-performance aircraft, Gulfstream aircraft, and Super Guppy transport aircraft.

SFCO also determines the need for and selects astronaut candidates. It takes approximately two years from the decision to select a new astronaut class until the selection process is completed. Once selected, new astronauts must complete two years of training for eligibility and then 30 months of ISS training before qualifying for an ISS mission. The number of spacecraft seats U.S. astronauts will fill in the next four years of human space flight determines the manifest requirement. The manifest includes projected Commercial Crew flights to ISS, Commercial Crew test flights, and Artemis flights. Requirements for future missions, for example to Gateway and the Moon, will be planned as those missions become better defined.

HUMAN SPACE FLIGHT OPERATIONS

Astronaut space flight readiness training activities, implemented by SFCO, put the crew into operational environments which share some aspects of the fast dynamics, physical stress, and risk found in spaceflight. The training develops the skills and ability to work as a team in an environment that is fast-paced, stressful, and carries potentially severe penalties for failure. The training also includes developing the skills necessary to respond in an emergency/high-stress environment and operate a high-performance aircraft.

CREW HEALTH AND SAFETY (CHS)

CHS enables healthy and productive crew during all phases of spaceflight missions, implements a comprehensive astronaut occupational health care program, and works to understand, prevent, and mitigate negative long-term health consequences from exposure to the spaceflight environment. Using HRP research and other findings, CHS implements enhancements to astronaut occupational health protocols to ensure crew health and safety. In this collaboration, HRP concentrates on the research aspects of crew health, whereas CHS focuses on implementing the research results and mitigation plans into occupational health protocols. As research continues on ISS, CHS is actively seeking new approaches to apply research findings to improve NASA health protocols, including collaborative opportunities with other Federal agencies and academia. Further, CHS is implementing the TREAT Astronauts Act for former astronauts. This Act enables NASA to provide monitoring, diagnosis, and treatment to astronauts for spaceflight-related medical issues following retirement from NASA. In addition, NASA will be able to obtain more medical data to supplement the occupational surveillance program for former astronauts and better assess the long-term effects of spaceflight on the human body to enable exploration.

CHS is also responsible for maintaining the health of active astronauts during non-mission periods, focusing on three aspects of health care: preventive care, risk factor management, and long-term health monitoring. CHS integrates and coordinates information relevant to human health before, during, and after spaceflight. CHS documents and assesses all emerging health risks, such as Spaceflight Associated Neuro-ocular Syndrome (a spaceflight condition that affects astronauts eye structure and can lead to impaired vision), and the risk of venous flow changes. CHS continues to collaborate with several non-NASA organizations, including the National Academies, to inform the risk decisions associated with long-duration and exploration missions.

Program Schedule

Date	Significant Event
FY 2022	Restart the annual Lifetime Surveillance of Astronaut Health (LSAH) exams (suspended due to Covid-19) with the goal of reaching 75 percent of former astronauts
FY 2022	Train ASCANs selected in FY 2022

Program Management & Commitments

Program Element	Provider
SFCO	Provider: SFCO Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): N/A
CHS	Provider: CHS Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): N/A

Acquisition Strategy

The section below identifies the current contract(s) that support SFCO and CHS.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Aircraft Logistics, Integration, Configuration and Engineering	Yulista Tactical	Ellington Field, Houston, TX El Paso, TX
Human Health and Performance Contract	KBR	Houston, TX

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	NCRP	Feb 2016	The NCRP conducted a Phase I review of potential central nervous system (CNS) effects from radiation exposure during space activities.	NCRP Commentary Report 25: Potential Central Nervous System Risks Following Space Radiation Exposure	Phase II completed November 4, 2019
Performance	National Academies of Sciences, Engineering, and Medicine	Oct 2020 - Aug 2021	Assessment of Strategies for Managing Cancer Risks Associated with Radiation Exposure During Crewed Space Missions	Report - Space Radiation and Astronaut Health: Managing and Communicating Cancer Risks (Published August 2021)	2026
Performance	National Council on Radiation Protection (NCRP) and Measurements	January 2022	To prepare a commentary that evaluates sex-specific differences in lung cancer radiation risks and assesses their use in transfer models and lifetime risk projections, with accompanying recommendations for NASA.	Report: Evaluation of Sex-Specific Differences in Lung Cancer Radiation Risks and Recommendations for Use in Transfer and Projection Models (Anticipate publication in June 2022	2027

HUMAN RESEARCH PROGRAM

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**115.0**	**130.2**	**151.2**	**151.2**	**152.0**	**147.0**	**147.1**
Change from FY 2022 Budget Request			**21.0**				
Percent change from FY 2022 Budget Request			**16.1%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

NASA astronaut Kate Rubins, the first to sequence Deoxyribonucleic acid (DNA) in space, eventually sequenced more than 2 billion base pairs of DNA during Expedition 48. During Expedition 64, Rubins conducted new DNA sequencing.

Sending astronauts into space involves a multitude of complicated systems, but perhaps the most complex is the human system – human health, human factors (i.e., how crews interact with their environment, including the spacecraft, habitat, and systems during missions), and the crew interactions. While NASA has more than 50 years of crew experience in low-Earth orbit (LEO), researchers are continuing to unravel the mysteries of how the human body responds to the harsh environment of space. The Human Research Program (HRP) is responsible for understanding and mitigating the highest risks to astronaut health and performance to ensure crews remain healthy and productive during long-duration missions beyond LEO.

As NASA prepares to conduct crewed missions via the Artemis campaign to cislunar space and the lunar surface, HRP is developing the scientific and technological capabilities to support these exploration missions. In support of the risk reduction strategy for human space exploration contained in the human research roadmap, HRP is coordinating with the National Academies, the National Council on Radiation Protection and Measurements (NCRP), and other domestic and international partners to deliver products and strategies to protect crew health and performance during and after exploration spaceflight missions. Current research on the International Space Station (ISS) in LEO and in ground-based analog laboratories is expanding NASA's capabilities to enhance crew performance and protect the health and safety of astronauts. Investigations regarding space radiation protection, deep space habitat systems, behavioral health, innovative medical technologies, advanced food and pharmaceutical systems, space suit requirements, and validated countermeasures are evolving to ensure crew health. HRP also collaborates with NASA's Office of Chief Health and Medical Officer (OCHMO) and the Crew Health and Safety (CHS) and Spaceflight Crew Operations (SFCO) offices to research these issues and answer other questions to ensure crew health, safety, and mission success. SFCO and CHS are responsible for astronaut training, readiness, and health, while HRP funds research development on human health and performance countermeasures, knowledge, and technologies that enable safe, reliable, and productive human space exploration.

Space poses significant health risks for crewmembers, including the possibility of long-term health effects manifesting later in life from space radiation exposure, health and performance decrements developing during the mission, and decrements in capabilities immediately upon return to Earth. HRP is working with the Exploration Capabilities (EC), CHS, and Orion teams on both in-mission and post-mission countermeasures, medical treatment capabilities to maximize crew health and performance, and rehabilitation protocols to minimize residual impacts on the crew, to minimize exposures, and to provide radiation protection. The collaborative efforts involve defining permissible exposure limits, requirements for real-time medical response, optimized mission architectures, biomedical monitoring, and potential drug or nutritional countermeasures, as well as incorporating post-mission health surveillance to ensure that crewmembers can safely live and work in space without exceeding acceptable health risks.

In collaboration with other Federal agencies, such as the Department of Defense (DoD), the Department of Energy (DOE), the National Science Foundation (NSF), the Department of Health and Human Services (HHS), and the National Institutes of Health (NIH), HRP supports human research to increase NASA's understanding of the effects of spaceflight on human physiological systems, behavioral responses to isolation and confinement, and space radiation health effects. This knowledge enables NASA's plans for long-duration human space missions beyond LEO. In addition, as is the case with many space-based medical investigations, this research may lead to significant advancements in treating patients on Earth.

EXPLANATION OF MAJOR CHANGES IN FY 2023

HRP's budget was increased to enable additional studies in support of the Artemis campaign.

ACHIEVEMENTS IN FY 2021

HRP continued to work on the highest human health and performance risk areas associated with human space exploration missions. To support this work, HRP released NASA research solicitations to the national biomedical research community to better address the exploration spaceflight health, performance, and space radiation risks.

HRP continued implementing a research plan that fully utilized the ISS biomedical research capabilities to collect a set of core measurements related to many human spaceflight risks, study the effects of diet quality on immune regulation, and assess the performance capabilities of deconditioned crew. HRP collaborated with CHS on ISS studies related to visual impairment, carbon dioxide analysis, and exercise systems; leveraged resources and expertise through collaborative research with other NASA programs, international partners, and other U.S. agencies (e.g., DoD, DOE, NSF, HHS, NIH).

HRP implemented an ISS research plan that fully utilized the ISS biomedical research capabilities to test mitigation approaches and validate countermeasures including the following: 1) technology demonstration of hardware to differentiate and count white blood cells in microgravity; 2) assessment of astronauts' post-landing functional capacity; 3) researching the effects of diet quality on immune regulation, profile of the gut microbiota, and nutritional biomarkers and metabolites; and 4) HRP-sponsored rodent study to determine whether microgravity alters the structure and function of the ocular vasculature in mice.

In support of exploration medical capabilities, HRP continued to develop an improved trade study evaluation and research prioritization tool suite to provide a data-driven means to inform human health and performance risk mitigation interests during resource-constrained exploration mission development. HRP evaluated a commercial-off-the-shelf flow cytometer device on ISS to determine whether the spaceflight environment affects its operation. HRP also continued to develop a clinical decision support system, which will help crews assess and diagnose conditions, determine appropriate responses, and guide treatment.

HRP and Deutsches Zentrum für Luft- und Raumfahrt (German Space Agency - DLR) finalized preparations for a bed rest study to assess the effectiveness of different countermeasures to mitigate the Spaceflight Associated Neuro-ocular Syndrome (SANS) symptoms observed in prior bedrest studies using the DLR: envihab facility.

In understanding the behavioral and physiological health challenges associated with isolation and confinement, HRP continued implementing collaborative NASA/NSF human health and performance studies on the effects of remote location, extreme isolation, and confinement during winter-over missions in Antarctica using the NSF polar stations. Other behavioral analogs were delayed to FY 2022 due to COVID-19.

In support of Artemis and future exploration missions, HRP met with all the Program Managers of Artemis-related activities to discuss areas where HRP could reduce risk or provide additional trade space for these developments. HRP initiated at least one project with each Program that were specifically requested by those Programs. Examples include validating requirements for Orion's waste management system, evaluating different carbon dioxide (CO2) levels for contingency surface Extravehicular Activity (EVA) scenarios, development of a Gateway Crew Health and Performance System, and autonomy standards for the new Lunar Terrain Vehicle (LTV) project. Further, HRP continued to work with Gateway and Artemis on planning its first human research payloads for the initial Artemis missions to Gateway and the lunar surface. HRP integrated all international partner human research payloads for the initial Gateway missions.

Through HRP's Translational Research Institute for Space Health (TRISH) cooperative agreement, HRP has begun to build relationships with entities involved in commercial spaceflight. HRP funded research (via TRISH) was accomplished on SpaceX's Inspiration4 mission. This set the precedent for commercial spaceflight missions in the future to include human research opportunities for its customers. TRISH has made agreements that will enable human research with commercial partners such as SpaceX, Blue Origin, Sierra Space, Space Adventures, and Axiom.

HRP continued to work on the highest human health and performance risk areas associated with human space exploration missions. To support this work, HRP released 18 NASA research solicitations and directed studies to the national biomedical research community to better address the exploration spaceflight health, performance, and space radiation risks.

WORK IN PROGRESS IN FY 2022

HRP will implement an ISS flight research plan critical to mitigating crew health and performance risks for Artemis missions that includes the following: ISS Standard Measures Project to capture a core set of physiological and performance measures from crew members to accurately characterize the adaptive responses to long-duration spaceflight and monitor the effectiveness of countermeasures; a microbial risk assessment study to ensure crew safety and allow increased dependence on bioregenerative food systems; a study to analyze the relationship between the increased microbial virulence and reduced human immune function commonly observed during orbital spaceflight; and a technology demonstration of the rHEALTH ONE system which will establish if this technology can identify and analyze biomarkers, cells, microorganisms, and proteins in the spaceflight environment. HRP also plans to implement an ISS research project to characterize the time courses of physiological and psychological measures on missions up to one year in duration to understand the impact to human health and performance during future long-duration planetary missions. This project will be known as CIPHER - Complement of Integrated Protocols for Human Exploration Research.

HRP and DLR will implement a bed rest study to assess the effectiveness of different countermeasures to mitigate the SANS symptoms observed in prior bedrest studies using the DLR: envihab facility. During the new campaign, the subjects will evaluate the effectiveness of lower body negative pressure (LBNP), thigh cuffs and exercise as countermeasures. Investigators will compare subjects with head-down bed rest or seated only to subjects experiencing head-down bedrest in combination with countermeasures on aspects such as ocular measures, cerebral measures, cognition, neuroimaging, and structural and functional Magnetic Resonance Imaging (MRI).

HRP is committed to understanding the behavioral and physiological health challenges associated with isolation and confinement, and therefore, the program will continue the 45-day Human Exploration Research Analog (HERA) studies at Johnson Space Center (JSC). In addition, the Scientific International Research in Unique Terrestrial Station (SIRIUS) 21 mission provides the environment for crew members to further conduct behavioral experiments on behalf of nearly 70 different researchers from around the world, including eight studies funded by HRP over the course of an 8-month mission spent isolated in the Nezemnyy Eksperimental'nyy Kompleks (NEK) facility.

HRP will leverage resources through multiple research partnerships, including advanced food and nutrition studies with DOD, behavioral and physiological studies during winter over campaign at NSF polar facilities, isolation and confinement studies with Russia, bed rest studies at the DLR: envihab facility, and develop joint flight research and data sharing with international partners.

HRP also engages in research to support future Artemis missions by working closely with the Artemis Campaign, OCHMO and Flight Operations Directorate to understand high priority human health and performance areas where HRP can contribute research to reduce those Programs' risk posture. HRP will continue to refine its initial Artemis payload planning as those missions evolve. HRP will continue to define its strategic research needs on the Artemis platform in collaboration with SOMD/ESDMD and AES SE&I organizations.

Through HRP's TRISH cooperative agreement, HRP will continue to foster and grow commercial spaceflight's ability to support human research activities. For all commercial spaceflight opportunities that are orbital, TRISH plans a suite of experiments to set a precedent for those companies to be able to offer those experiences to their customers. Strategically, this will likely open up additional subjects and platforms to help HRP accelerate its research goals.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

HRP is developing Informing Mission Planning via Analysis of Complex Trade spaces (IMPACT) to assist SOMD/ESDMD and OCHMO/HMTA in understanding the impacts of mission design and vehicle resource allocation on medical risk for long duration lunar missions via the Artemis Campaign. IMPACT is an integrated computational tool suite used by ground personnel to perform complex trade space analysis and enable decision-making about medical system design and content. It also maps potential medical systems against Model-Based Systems Engineering (MBSE) medical system requirements to enable informed trades between them. IMPACT supports data-driven and evidence-based decision-making throughout the entire mission life-cycle and it is a significant evolution from the current Integrated Medical Model (IMM) used for ISS/LEO medical kit decision making.

HRP intends to characterize the relationship between the headward fluid (blood, interstitial, cerebrospinal) shift and structural and functional changes observed in the eye and brain of ISS astronauts, a condition referred to as SANS. Over 70 percent of ISS astronauts exhibit signs of SANS during or after ISS missions, including optic disc edema, choroidal folds and increased brain ventricle volumes. While vision is correctable to 20/20 inflight, the long-term health consequences of chronic exposure to optic disc edema or enlarged brain ventricles are unknown and may be of consequence. The primary hypothesis for these morphological changes is the sustained headward fluid shift that all astronauts experience, although it is unclear why not all crew experience the same magnitude of change. Characterization of the relationship between SANS and these headward fluid shifts will help drive countermeasure development (i.e., lower body negative pressure or venoconstrictive thigh cuffs to reverse the fluid shift).

HRP will conduct a ground study to characterize the limit of acceptable performance (physical and cognitive) decrements and symptom severity for mission operations when subjected to elevated inspired CO2 levels (up to 30 mmHg). Inspiring elevated partial pressures of CO2 can cause both physical and cognitive decrements. The task will qualitatively evaluate the severity of symptoms if they occur, whether symptoms require walk-back termination, and the timeline for resolution of those symptoms across a range of inspired CO2 levels. This information will be vital for vehicle and suit design for upcoming exploration missions, and these results will be used to inform a new NASA standard as well as Exploration Extravehicular Mobility Unit (xEMU) requirements for suited contingency inspired CO2 levels.

HRP will conduct a study of astronauts within two hours, and in the hours and days upon their return to Earth to evaluate functional performance. Measurable performance parameters such as the ability to perform a seated egress, recover from a fall, and other performance tasks will be used to establish a sensorimotor time constant for the recovery from observed decrements. Results of this study will identify sensorimotor changes as the result of long duration spaceflight and allow individually tailored interventions to prevent injury when ground personnel cannot assist flight crews.

Program Elements

EXPLORATION MEDICAL CAPABILITY

As NASA makes plans to extend human exploration beyond LEO, identifying and testing next generation medical care and crew health maintenance technologies is vital. Healthcare options evolve based on experience, anticipated needs, and input from flight surgeons and crew offices. During future Mars missions, crews will not be able to rely on real-time conversations with Earth-based medical experts in the future due to communication lag-time associated with the distance between Earth and deep space. Therefore, crew and relevant systems will have to be able to facilitate autonomous medical care operations. Teams in this area draft requirements for medical equipment and clinical care, develop remote medical technologies, and assess medical requirements unique to long-duration space missions.

HUMAN HEALTH COUNTERMEASURES

Countermeasures are the procedures, medications, devices, and other strategies that offset the impacts of spaceflight stressors (e.g., low-gravity, closed environment) and help keep astronauts healthy and productive during space travel and after their return to Earth. Researchers are responsible for understanding the normal physiologic effects of spaceflight and provide biomedical expertise and develop countermeasures to harmful effects on human health and performance. These experts define health and medical standards; validate human health prescriptions and exercise system requirements; develop injury and sickness prevention standards; integrate and validate physiological countermeasures; and establish criteria for NASA fitness for duty, as well as crew selection and performance standards.

HUMAN FACTORS AND BEHAVIORAL PERFORMANCE

Just as the space environment poses physical risks to crewmembers, the unique stresses and challenges of spaceflight, as well as the vehicle design, can affect cognitive and mental performance. Considering external factors is essential when designing a spacecraft, habitat, or spacesuit. Human factors experts develop new equipment, procedures, and technologies designed to make the space environment more livable. Behavioral health researchers assess the impact of space travel on human behavioral health and develop interventions and countermeasures to ensure optimal health and performance. Experts in this area make extensive use of analogs, which are experimental environments created to simulate certain aspects of space travel. By duplicating space conditions, such as altered day and night cycles, heavy workloads, social isolation, and close living quarters, scientists gain insight into the impact of these circumstances on human behavior and performance. Scientists then work to develop countermeasures, equipment, and other interventions to minimize these risks.

SPACE RADIATION

As NASA expands human presence beyond the Earth's protective magnetic field, it is critical that astronauts be able to safely live and work in a space radiation environment. Space radiation researchers develop the knowledge base necessary to determine the biological effects of space radiation. This information can then be used for standards for health and habitability and the requirements for radiation protection. They also develop tools to assess and predict risks due to space radiation exposure and strategies to mitigate exposure effects. The deep space radiation environment is far different from that on Earth or in LEO. NASA and the DOE have partnered on a facility at Brookhaven National Laboratory in Upton, NY, to simulate the deep space radiation environment, which researchers use to help understand its biological effects.

RESEARCH OPERATIONS AND INTEGRATION

The ISS provides a unique testbed for HRP activities. The Research Operations and Integration (ROI) element plans, integrates, and implements HRP-approved biomedical flight experiments on the ISS, as well as research studies that use ground-based spaceflight analog facilities to accomplish program objectives. These experiments and studies pertain to pre- and post-flight activities, and the program objectives include coordinating flight or ground resources with our international partners, maintaining the Human Research Facility (HRF) biomedical research racks on ISS and flight hardware, and developing crew training for both flight and ground investigations. Teams also operate a Telescience Support Center (TSC), which provides real-time support and data services to all HRP flight experiments. Strong interfaces with external implementing organizations, such as the ISS Research Integration office, analog coordination offices, and international partners, are critical to maintaining a robust research program. This group is also responsible for operating the HERA facility and for arranging access to other analog facilities required by HRP researchers, including NSF Antarctic facilities and international partner facilities in Germany and Russia.

MATURATION AND INTEGRATION OFFICE

In FY 2021, HRP stood up this new office. The Maturation and Integration Office (MIO) has the responsibility for coordinating the Human Research Program's research and technology deliverables with its stakeholders. This office provides strategic planning for Artemis, Mars, and Commercial Spaceflight research opportunities. This office further fosters relationships with OCHMO, Artemis Campaign, and the Flight Operations Directorate (FOD) to ensure HRP is addressing high priority operational research questions that can reduce risks or provide additional trade space for those organizations. As OCHMO and the Agency stand up a recognized "Crew Health and Performance System" for exploration missions, this office will integrate models and technology deliverables along with our operational spaceflight partners.

Program Schedule

Date	Significant Event
Feb 2022	2021 Human Exploration Research Opportunity (HERO) NASA Research Announcement Selections
Mar 2022	Release 2022 HERO NASA Research Announcement
Mar 2022	Deliver Artemis II Payload Science Plans
Mar 2023	Deliver Artemis III Payload Science Plans
Apr 2023	SANS Fluid Shift Hypothesis Characterized

Program Management & Commitments

The program office is located at JSC with support from Ames Research Center (ARC), Glenn Research Center (GRC), Langley Research Center (LaRC), and Kennedy Space Center (KSC).

The SOMD/ESDMD Associate Administrator delegated the authority, responsibility, and accountability of HRP management to the Human Spaceflight Capabilities Division at NASA Headquarters. Working closely with the Office of the Chief Scientist and the OCHMO, the Division establishes the overall direction, scope, budget, and resource allocation for the program, which the NASA centers then implement.

Program Element	Provider
Exploration Medical Capability	Provider: JSC Lead Center: JSC Performing Center(s): GRC, ARC, and LaRC Cost Share Partner(s): N/A
Human Health Countermeasures	Provider: JSC Lead Center: JSC Performing Center(s): ARC and GRC Cost Share Partner(s): N/A
Human Factors and Behavioral Performance	Provider: JSC Lead Center: JSC Performing Center(s): ARC, GRC, and KSC Cost Share Partner(s): N/A
Space Radiation	Provider: JSC Lead Center: JSC Performing Center(s): LaRC Cost Share Partner(s): N/A

HUMAN RESEARCH PROGRAM

Program Element	Provider
Research Operations and Integration	Provider: JSC Lead Center: JSC Performing Center(s): N/A Cost Share Partner(s): N/A
Maturation and Integration Office (MIO)	Provider: JSC Lead Center: JSC Performing Center(s): ARC and GRC Cost Share Partner(s): N/A

Acquisition Strategy

Based upon National Academies' recommendations, external peer reviews, and Agency human exploration plans, NASA HRP awards contracts and grants to further efforts in mitigating risks to crew health and performance by providing essential biomedical research and technologies for human space exploration. HRP uses a peer review process that engages leading members of the research community to competitively assess the merits of submitted proposals to assure a high-quality research program.

HRP plans to release the HERO umbrella NASA Research Announcement (NRA) that will request research proposals across all its research elements throughout the year. This NRA provides opportunities for universities, other Government agencies, and industry researchers from across the Nation to develop high NASA priority ground and spaceflight experiments, which directly contribute to NASA's exploration mission.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Program Management	Translational Research Institute for Space Health	Baylor College of Medicine
Research Operations and Integration	Deutsches Zentrum für Luft- und Raumfahrt (German Space Agency - DLR)	Envihab facility in Cologne, Germany
Space Radiation	United States Department of Energy	Brookhaven National Laboratory

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	Independent Program Assessment	Jun 2019	Review of program management policies and practices.	Verify adherence to NASA program management policies.	Jul 2024
Quality	Peer Review Panel	Feb 2021	Peer review of NRA.	Selected grantees	Feb 2022
Quality	National Council on Radiation Protection and Measurements (NCRP)	Jan 2022	Sex-differences in Lung Cancer Radiation Risks for use in Project Models.	Reduced uncertainties and improved information for cancer risk projections.	TBD

LAUNCH SERVICES

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**91.9**	**102.7**	**93.9**	**94.3**	**94.8**	**94.8**	**94.9**
Change from FY 2022 Budget Request			**-8.8**				
Percent change from FY 2022 Budget Request			**-8.6%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

An Atlas V rocket (shown here) lifts off from Space Launch Complex 41 at Cape Canaveral Space Force Station in Florida on October 16, 2021, at 5:34 a.m. EDT, carrying NASA's Lucy spacecraft.

NASA's science and discovery missions, civil communications, geographic survey, and civil weather missions provide key services for our Nation and the world. The Launch Services Program (LSP) ensures access to space for the Nation's civil sector satellite and robotic planetary missions.

The National Space Transportation Policy identifies the NASA Administrator as the launch agent for the Nation's civil sector. LSP enables the Administrator to execute this role by acquiring and managing domestic commercial launch services for assigned missions, certifying new commercial launch vehicles for readiness to fly high-value spacecraft, performing mission design and launch integration activities, and directing launch mission assurance efforts to ensure the greatest probability of launch mission success. While no space mission is routine, LSP has unique launch system expertise involving payloads containing nuclear power sources for launching one-of-a-kind science exploration missions to other planets, the Sun, or other locations in space. NASA relies on LSP to provide robust, reliable, and cost-effective launch services via commercial launch providers. NASA achieves assured access to space through a competitive mixed-fleet approach utilizing the breadth of U.S. industry capabilities. In addition, LSP provides launch-related expertise to other NASA programs, such as Commercial Resupply Services (CRS), Commercial Crew Program (CCP), and programs supporting the Artemis Campaign. LSP also provides launch advisory support to NASA payload missions using launch services through other Government agencies, the launch industry, or contributed by a foreign partner.

In addition to acquiring the commercial launch service, LSP arranges pre-launch spacecraft processing facility support and communications and telemetry during ascent for its customers. LSP offers insight into the commercial space launch industry, which has been utilized by CCP. LSP also tracks lessons learned to identify and mitigate risks for future managed launches and certifies the readiness of new commercial launch vehicles for NASA and other civil sector uncrewed spacecraft. The program also conducts engineering analyses and other technical tasks to maximize launch success for every assigned payload.

LAUNCH SERVICES

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

ACHIEVEMENTS IN FY 2021

LSP provided expertise and active launch mission management for over 70 NASA scientific spacecraft missions in various stages of development. LSP continuously works with the U.S. commercial launch industry to assess their designs and provide advice, which expands the selection of domestic launch vehicles available to NASA's missions and nurtures a competitive commercial launch service environment. LSP successfully launched two science missions, as shown in the table below. In addition, Virgin Orbit successfully launched 10 NASA CubeSats to low-Earth orbit on the LauncherOne launch vehicle (the second mission under the original Venture Class Launch Services (VCLS) contract) on January 17, 2021.

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
Nov 2020 Vandenberg Space Force Base, CA	Falcon 9 Full Thrust	Sentinel 6 Michael Freilich	NASA Science Mission Directorate (SMD)	To measure sea surface topography with high-accuracy and reliability to support ocean forecasting systems, environmental monitoring. and climate monitoring. The mission provides continuity of the TOPEX and JASON missions and improvements in instrument performance and coverage.
Sep 2021 Vandenberg Space Force Base, CA	Atlas V	Landsat-9	NASA SMD	Landsat-9 is the latest satellite in the Landsat series, following its predecessor (Landsat-8). Landsat-9 will carry two science instruments that will continue the Program's observation of the Earth's land surface to reduce the build time and risk of a gap in observations.

LSP acquired new launch services for three future missions through competitively awarded launch service task orders:

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
Apr 2024 Kennedy Space Center, FL	Falcon Heavy	GOES-U	NOAA	Geostationary Operational Environmental Satellite-U (GOES-U) will provide advanced imagery and atmospheric measurements of Earth’s weather, oceans, and environment, as well as real-time mapping of total lightning activity and improved monitoring of solar activity and space weather.

LAUNCH SERVICES

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
Jun 2024 Vandenberg Space Force Base, CA	Falcon 9 Full Thrust	SPHEREx	NASA SMD	Spectro-Photometer for the History of the Universe, Epoch of Reionization, and Ices Explorer (SPHEREx) is an astrophysics mission to survey the sky in the near-infrared light, which, though not visible to the human eye, serves as a powerful tool for answering cosmic questions involving the birth of the universe, and the subsequent development of galaxies.
Nov 2024 Kennedy Space Center, FL	Falcon Heavy	PPE + HALO	NASA Exploration Systems Development Mission Directorate (ESDMD)	Power and Propulsion Element (PPE) and Habitation and Logistics Outpost (HALO) are the foundational elements of the Gateway. As the first long-term orbiting outpost around the Moon, the Gateway is critical to supporting sustainable astronaut missions under the Agency's Artemis Campaign.

** Launch Dates shown in this table correspond to launch dates listed as Management Agreements elsewhere in this document.*

LSP continued partnering with several universities and NASA centers to launch small research satellites through the CubeSat Launch Initiative (CSLI), which provides rideshare opportunities for small satellite payloads to fly on upcoming launches when excess capacity is available. These partnerships have provided regular educational opportunities for students in Science, Technology, Engineering, and Mathematics (STEM) disciplines, which help strengthen the Nation's future workforce. To date, CubeSats have been selected from 42 states, the District of Columbia, and Puerto Rico, with 124 missions launched and 38 manifested on NASA, National Reconnaissance Office, U.S. Air Force, and commercial missions. In FY 2021, 20 CSLI CubeSat missions were launched. In addition to awarding VCLS and CSLI contracts, NASA also awarded two other one-off contracts for Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) and Europa Clipper missions. TROPICS, a small class mission requiring six CubeSats to be placed in three different operational orbits, was awarded to Astra Space, Inc. for a Rocket 3 launch service. Europa Clipper, a planetary science flagship mission in the intermediate/heavy class, was awarded to Space-X for a Falcon Heavy launch service.

In December 2020, Blue Origin's New Glenn launch service was successfully on-ramped to the NASA Launch Services (NLS) II contract. In April 2021, United Launch Services (ULS) successfully on-ramped their Vulcan Centaur launch vehicle. Both launch vehicles were on-ramped as part of the ninth NLS II on-ramp activity. During this on-ramp solicitation process, Northrop Grumman Innovation Systems (NGIS) initially submitted a proposal to on-ramp their OmegA launch vehicle but withdrew their proposal once they decided to terminate the OmegA program. ULS also formally notified NASA LSP of their intention to off-ramp their Delta IV-Medium and Delta IV-Heavy launch vehicles. This off-ramp has been completed and therefore Delta IV-Medium and Delta IV-Heavy are no longer on the NLS II contract. In August 2021, ULA publicly announced that they had sold out their entire remaining inventory of Atlas V launch vehicles and would no longer be offering the Atlas V for future acquisitions. The 2022 NLS II on-

LAUNCH SERVICES

ramp activity is scheduled to commence in early 2022. The Delta II Closeout/Space Launch Complex (SLC) 2 Demolition work continued at Vandenberg Space Force Base (VSFB) in California. Demolition of the Mobile Service Tower was completed in December 2020, and the SLC-2 launch pad was turned over to the Space Force who then leased the pad to Firefly. Along with the launch pad, there are 16 real properties (buildings across the greater SLC-2 complex that needs to be demolished at NASA's cost). A contract was awarded by the 30th Space Wing in September 2021 to demolish three of the 16 buildings that NASA is responsible to demolish per the cost sharing agreement signed between NASA and the United States Air Force (now known as the United States Space Force) in May 2019.

WORK IN PROGRESS IN FY 2022

LSP will continue mission design and launch integration support to over 70 missions in various stages of development. In addition to launch preparation activities for one mission that will launch in FY 2023, the current manifest for FY 2022 shows LSP will manage and conduct launch activities for six NASA missions contracted under NLS II, in addition to the TROPICS and the Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) CubeSat missions which were contracted outside of NLS II to meet the special needs of those missions. CAPSTONE will serve as a pathfinder for the lunar spaceship Gateway, a key component of NASA's Artemis Campaign.

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
Oct 2021 Cape Canaveral Space Force Station, FL	Atlas V	Lucy	NASA SMD	A planned NASA space probe that will tour five Jupiter trojans, asteroids which share Jupiter's orbit around the Sun, orbiting either ahead of or behind the planet, and one main belt asteroid.
Nov 2021 Vandenberg Space Force Base, CA	Falcon 9 Full Thrust	Double Asteroid Redirection Test (DART)	NASA SMD	Demonstrates kinetic impactor technology impacting an asteroid to adjust its speed and path. DART will be the first-ever space mission to demonstrate asteroid deflection by kinetic impactor.
Dec 2021 Kennedy Space Center, FL	Falcon 9 Full Thrust	Imaging X-ray Polarimetry Explorer (IXPE)	NASA SMD	Exploits the polarization state of light from astrophysical sources to provide insight into our understanding of X-ray production in objects (e.g., neutron stars, pulsar wind nebulae), as well as stellar and supermassive black holes.
Mar 2022 Cape Canaveral Space Force Station, FL	Atlas V	GOES-T	NASA SMD	GOES-T is the third of the GOES series next generation of weather satellites operated by NOAA that will extend the availability of the GOES satellite system until 2036.

LAUNCH SERVICES

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
Mar 2022 - May 2022 (3 in 120 days) Cape Canaveral Space Force Station, FL	Rocket 3	TROPICS	NASA SMD	The CubeSats, each the size of a shoebox, will provide rapid-refresh microwave measurements that can be used to determine temperature, pressure, and humidity inside hurricanes as they form and evolve. The TROPICS mission's high-revisit imaging and sounding observations are enabled by microwave technology developed at the Massachusetts Institute of Technology's Lincoln Laboratory. These observations will profoundly improve scientists' understanding of processes driving high-impact storms.
Aug 2022 Kennedy Space Center, FL	Falcon Heavy	Psyche/Janus (2nd)	NASA SMD	Psyche is a NASA interplanetary mission to visit the main belt asteroid "16 Psyche". The Spacecraft will take four years and one Mars flyby to reach the asteroid, which is comprised mostly of iron and nickel.
Sep 2022 Vandenberg Space Force Base, CA	Atlas V	Joint Polar Satellite System (JPSS)-2/ Low-Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID) (2nd)	NASA SMD	JPSS-2 is a continuation of the JPSS series of satellites that will capture precise observations of the world's atmosphere, land, and waters, and provide data that inform seven-day forecasts and extreme weather events.

** Launch Dates shown in this table correspond to launch dates listed as Management Agreements elsewhere in this document.*

LSP will continue to actively acquire new launch services for future NASA missions.

All three missions awarded under VCLS Demo 2 are planned for launch in FY 2022, as shown in the table below. The VCLS Demo 2 contracts awarded two types of missions which are referred to in the contract as a Mission One and a Mission Two. Mission One is for a dedicated launch service for CubeSats that includes a single launch with a delivery of 30 kg payload mass to 500 km at an inclination between 40-60 degrees. Mission Two is for a single launch service with CubeSats as the primary payload. Mission Two includes a single launch with a delivery of a Constellation A (75 kg payload mass) and a Constellation B (20 kg payload mass) to 550 km and includes a minimum 10-degree plane change between constellations. The VCLS Demo 2 companies and their respective awarded missions are: Astra Space Inc. of Alameda, California (Mission One); Relativity Space Inc. of Long Beach, California (Mission One); and Firefly Black LLC of Cedar Park, Texas (Mission Two).

LAUNCH SERVICES

Launch Date/Location*	Launch Vehicle	Payload	Customer	Mission Objectives
Dec 2021 Cape Canaveral Air Force Station, FL	Astra Space, Inc. Rocket 3	VCLS Demo 2 (Mission One: 30 kg payload, 500 km @ 41 deg inclination)	NASA, one STEM school, and multiple universities	A demonstration flight to determine if new small launch vehicles can deliver NASA payloads to orbit at a fixed price.
NLT June 2022 Vandenberg Air Force Base, CA (SLC-2)	Firefly Black LLC Alpha	VCLS Demo 2 (Mission Two: (1) 75 kg payload, 550 km SSO (2) 20 kg to 550 km SSO w/ min 10-degree plane change)	NASA, one STEM school, and multiple universities	A demonstration flight to determine if new small launch vehicles can deliver NASA payloads to orbit at a fixed price.
Sep 2022 Cape Canaveral Air Force Station, FL (SLC-16)	Relativity Space Inc Terran 1	VCLS Demo 2 (Mission One: 30 kg payload, 500 km @ 41 deg inclination)	NASA, one STEM school, and multiple universities	A demonstration flight to determine if new small launch vehicles can deliver NASA payloads to orbit at a fixed price.

** Launch Dates shown in this table correspond to launch dates listed as Management Agreements elsewhere in this document.*

NASA has also selected 12 companies to provide launch services under the Venture-Class Acquisitions of Dedicated and Rideshare (VADR) contract. This contract will enable regular, competitive acquisition of commercial launch services for small payloads, such as those successfully demonstrated through the VCLS contracts. The VADR contract was awarded in FY 2022 and will provide a broad range of Federal Aviation Administration (FAA)-licensed commercial launch services capable of delivering payloads ranging from CubeSats to Class D missions to a variety of orbits. Firm-fixed-price task orders will be issued to provide the launch services under these contracts for NASA and NASA-sponsored missions. Launches under the VADR contract will align with commercial practices, using less NASA oversight to achieve lower launch costs. Award selections are:

- ABL Space Systems of El Segundo, California;
- Astra Space Inc. of Alameda, California;
- Blue Origin Florida LLC of Merritt Island, Florida;
- L2 Solutions LLC of Houston;
- Northrop Grumman Systems Corporation of Chandler, Arizona;
- Phantom Space Corporation of Tucson, Arizona;
- Relativity Space Inc. of Long Beach, California;
- Rocket Lab USA Inc. of Long Beach, California;
- Spaceflight Inc. of Seattle;
- Space Exploration Technologies Corp. (SpaceX) of Hawthorne, California;
- United Launch Services LLC of Centennial, Colorado; and
- Virgin Orbit LLC of Long Beach, California.

LAUNCH SERVICES

LSP will continue to provide advisory support, expertise, and knowledge to NASA programs and work towards certifying new commercial launch vehicles to launch high-value payloads. Certification activities are ongoing with ULS' Vulcan, SpaceX's Falcon Heavy, and Alpha's Firefly launch vehicles. Planning activities for certification of Blue Origin's New Glenn launch vehicle is also in work.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

LSP will continue to execute the role of launch agent for the NASA Administrator on behalf of the U.S. civil sector, as described in the National Space Transportation Policy. The Program will provide management of NASA Launch Services contracts, launch mission assurance, mission design, and launch integration support to scientific spacecraft missions in various development phases. The current manifest for FY 2023 shows LSP will manage and conduct launch activities for one NASA mission contracted under NLS II.

Launch Date/Location*	Launch Vehicle	Payload	Customer	Mission Objectives
Nov 2022 VAFB	Falcon 9	Surface Water and Ocean Topography (SWOT)	NASA SMD; Centre National D'Etudes Spatiales (CNES)	SWOT will collect detailed measurements of how water bodies on Earth change over time.

**FY 2023 Launch Dates shown in this table correspond to launch dates listed as Management Agreements elsewhere in this document.*

LSP will continue work towards certifying new commercial launch vehicles to launch high-value payloads, as needed, and will continue launch service acquisition activities necessary to support NASA and other approved Government missions.

Along with full end-to-end launch service management of awarded missions, LSP continues to offer advisory support, expertise, and knowledge to NASA programs and projects utilizing launch services not procured and managed by LSP. The program is currently providing these advisory and informational services to several programs and missions, including the:

- Gateway;
- ISS Cargo Resupply Service missions;
- Commercial Crew Program; and
- NASA-Indian Space Research Organization Synthetic Aperture Radar (NISAR) missions.

LAUNCH SERVICES

Program Management & Commitments

Program Element	Provider
Commercial Launch Vehicle (CLV) Launch Services	Provider: ULS, NGIS (formerly Orbital ATK), SpaceX, Rocket Lab USA, Virgin Orbit Lead Center: Kennedy Space Center (KSC) Performing Center(s): KSC Cost Share Partner(s): N/A

ACQUISITION STRATEGY

LSP's acquisition strategy was created for the original NLS contracts for procuring CLV launch services from domestic commercial launch service suppliers. To meet the needs of science and technology customers who typically spend three to seven years developing a spacecraft mission, NASA created a contractual approach providing multiple competitive launch service options to cover small-, medium-, intermediate-, and heavy-sized missions. The follow-on contract mechanism, known as NLS II, has similar contract features. These features include not-to-exceed prices, indefinite-delivery-indefinite-quantity contract terms, and competitive firm-fixed-price launch service task order-based acquisitions. The NLS II ordering period has been extended to June 30, 2025. To ensure active competition for NASA customers and encourage new launch capability development through these long-term contracts, NASA provides annual opportunities to U.S. industry to add new commercial launch service providers and/or launch vehicles to the contract.

LSP is also able to contract separately from the NLS contract mechanism if such an approach is necessary to meet a mission or customer need. For instance, the launch service for the Europa Clipper mission funded by NASA SMD is being competed outside and separate from the NLS II contract due to the special needs of that mission. In addition, VCLS awards for very small launch vehicles were conducted outside and separate from the NLS II contract to provide more flexibility to the new, small-class launch providers. Twelve companies were also selected to provide launch services under the VADR contract, which will have a five-year ordering period with a maximum total value of $300 million across all Indefinite Delivery/Indefinite Quantity contracts. The acquisition also includes a special on-ramp provision to enable additional providers and incumbents to submit proposals introducing launch services for new capabilities not available or identified at the time of the initial contract award.

NASA has also made efforts to provide a complete launch service, including payload processing at the launch site. LSP uses firm-fixed-price indefinite-delivery-indefinite-quantity contracts for commercial payload processing capabilities on both the East and West coasts. The Payload Processing Facility (PPF) contracts are up for recompete. The East Coast Commercial Payload Processing Contract-4 (ECCPP-4) was awarded in April 2017 and the period of performance ends in April 2022. The West Coast Commercial Payload Processing Contract-3 (WCCPP-3) solicitation was cancelled. LSP is currently awarding mission specific PPF contracts for those on the West coast.

LAUNCH SERVICES

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
NASA Launch Services II-Blue	Blue Origin	Kent, WA Kennedy Space Center, FL
NASA Launch Services-II-O	Northrop Grumman Systems Corporation (NGSC)	Dulles, VA
NASA Launch Services-II-S	SpaceX	Hawthorne, CA
NASA Launch Services-II-U	ULS, LLC	Centennial, CO
East Coast Commercial Payload Processing-4	Astrotech Space Operations	Titusville, FL
West Coast Commercial Payload Processing-Landsat 9 and JPSS-2	L3Harris Technologies, Inc.	Vandenberg Space Force Base, CA
Expendable Launch Vehicle Integrated Support (ELVIS) 3	a.i. Solutions, Inc.	Lanham, MD Kennedy Space Center, FL Cape Canaveral Space Force Station, FL Vandenberg Space Force Base, CA
Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) Launch Services	Astra Space Inc.	Alameda, CA
Europa Clipper Launch Services	SpaceX	Hawthorne, CA
Venture Class Demonstration 2 (VCLS Demo 2)	Astra Space Inc. Relativity Space Inc. Firefly Aerospace	Alameda, CA Long Beach, CA Cedar Park, TX

LAUNCH SERVICES

Element	Vendor	Location (of work performance)
Venture-Class Acquisitions of Dedicated and Rideshare (VADR)	ABL Space Systems Astra Space Inc. Blue Origin Florida LLC L2 Solutions LLC Northrop Grumman Systems Corporation Phantom Space Corporation Relativity Space Inc. Rocket Lab USA Inc. Spaceflight Inc. Space Exploration Technologies Corp. (SpaceX) United Launch Services LLC Virgin Orbit LLC	El Segundo, CA Alameda, CA Merritt Island, FL Houston, TX Chandler, AZ Tucson, AZ Long Beach, CA Long Beach, CA Seattle, WA Hawthorne, CA Centennial, CO Long Beach, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Program Implementation Review (PIR)	Standing Review Board (SRB)	May 2014	Life Cycle Review	The SRB found LSP is a successful program with a strong technical and management team representing NASA’s core competency, demonstrating exceptional performance with a 97.4 percent launch success record. The SRB recommended continuation of LSP operations as currently performed.	FY 2024*

**The FY 2024 milestone for LSP will be assessed by the Space Operations Mission Directorate (SOMD) Associate Administrator, and a determination will be made as to whether a PIR is required or if it can be delayed another five years. The FY 2024 milestone is also subject to change depending on LSP's manifest/launch schedule for that year.*

Historical Performance

LSP managed CLV Missions from inception (1998) through FY 2021:

Launch Vehicle Configuration	Provider	Number of Launches	Successful Launches	Unsuccessful Launches
Athena	Lockheed Martin/Alliant Techsystems	1	1	0
Atlas IIA	Lockheed Martin	5	5	0
Atlas IIAS	Lockheed Martin	1	1	0

LAUNCH SERVICES

Launch Vehicle Configuration	Provider	Number of Launches	Successful Launches	Unsuccessful Launches
Atlas V	Lockheed Martin	12	12	0
	ULS	8	8	0
Delta II	Boeing Launch Services	20	20	0
	ULS	15	15	0
Delta II H	Boeing Launch Services	3	3	0
	ULS	4	4	0
Delta IV H	ULS	1	1	0
Falcon 9 v1.1	Space X Launch Services	1	1	0
Falcon 9 FT	Space X Launch Services	3	3	0
Pegasus Hybrid	Northrup Grumman (formerly OSC)	1	1	0
Pegasus XL	Northrup Grumman (formerly OSC)	15	15	0
Taurus XL	Northrup Grumman (formerly OSC)	2	0	2
Titan II	Lockheed Martin	3	3	0

ROCKET PROPULSION TEST

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**47.6**	**47.8**	**48.2**	**48.5**	**48.7**	**48.8**	**48.8**
Change from FY 2022 Budget Request			**0.4**				
Percent change from FY 2022 Budget Request			**0.8%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Teams from NASA's Space Launch System (SLS) Program conducted a successful hot fire of the Artemis I core stage at NASA's Stennis Space Center on the B-2 Test Stand, which is maintained by the Rocket Propulsion Test Program.

Developing and testing rocket propulsion systems is foundational to spaceflight. Whether the payload is a robotic science experiment or a crewed mission, the propulsion system used to launch it must be safe and reliable. A rigorous engine test program is a critical component of any rocket propulsion development activity.

NASA's Rocket Propulsion Test (RPT) program maintains and manages a wide range of facilities capable of ground testing rocket engines and components under controlled conditions. This test infrastructure includes facilities located across the United States, and the program provides a single-entry point for any user of NASA rocket test stands. RPT retains a skilled workforce capable of performing tests on all modern-day rockets and supporting complex rocket engine development. RPT evaluates customer test requirements and desired outcomes while minimizing test time and costs. It also streamlines facility usage and eliminates redundant capabilities by closing and consolidating NASA's rocket test facilities, as appropriate.

RPT is NASA's implementing authority for rocket propulsion testing. It approves and provides direction on test assignments, capital improvements, and facility modernization and refurbishment to reduce propulsion test costs. RPT integrates multi-site test activities, identifies and protects core capabilities, and develops advanced testing technologies.

The Agency has designated RPT as the NASA representative for the National Rocket Propulsion Test Group (NRPTG), an inter-agency collaboration with the Department of Defense (DoD), to facilitate efficient and effective use of the Federal Government's rocket propulsion test capabilities. The NRPTG is a standing group within the Range Commanders Council (RCC). The RPT Program Manager serves as a co-chair of the NRPTA Senior Steering Group and appoints NASA's group chair. The group chair position is a rotational appointment which alternates with the DoD, and the NASA chair is chosen from primary center representatives of RPT's management board.

ROCKET PROPULSION TEST

For more information, go to: https://rpt.nasa.gov/

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

ACHIEVEMENTS IN FY 2021

RPT provided propulsion data to validate baseline designs, increase confidence in technical performance, reduce risks, and ensure launch readiness in preparations for Artemis I and Artemis II, as well as support toward Commercial Crew Program's (CCP) milestones. The most significant accomplishment was the successful hot fire of the Space Launch System (SLS) core stage. On March 18, 2021, the SLS fired its four RS-25 engines for 8 minutes and 19 seconds on the B-2 test stand at Stennis Space Center in Mississippi. This completed a series of Green Run tests to ensure the SLS core stage satisfied design objectives, a critical milestone ahead of the Agency's Artemis I mission. Another significant 2021 RPT achievement was completion of all seven of the Retrofit-2 RS-25 series tests. These tests culminated with the September 30th, A-1 Test Stand final test run on RS-25 developmental engine No. 0528. This test series provided data to enhance production of new RS-25 engines and several engine components that are being manufactured with cutting-edge and cost-saving technologies. The test campaign also ran the engine through a range of operating conditions to demonstrate and verify its capabilities. In the E-Complex, over 250 tests were completed in support of NASA and commercial partnerships for risk-reduction design demonstrations and hardware development campaigns. At Marshall Space Flight Center (MSFC), Test Stands 115 and 116 were active in completing a total of nearly 200 tests primarily for internal testing of developmental hardware, as well as commercial subscale and component testing. Personnel at the White Sands Test Facility (WSTF) competed a series of testing for the European Space Agency (ESA) Service Module and for the DoD in support of Minuteman Aging Surveillance Program. At Glenn Research Center, Armstrong Test Facility (GRC-ATF), work continued in preparation for the Sierra Nevada Corporation Dream Chaser Cargo System test and for environmental test of the HELIX integrated instrument payload sponsored by the NASA Balloon Program Office.

RPT facilities continued to evaluate and implement high-risk/high-priority facility maintenance and modernization projects to assure propulsion test assets are available to support current and future propulsion test requirements. Additionally, the program continued to conduct an analysis of anticipated future propulsion test needs with the goal to strategically prepare availability of the portfolio of test stands at the four centers for NASA's future.

WORK IN PROGRESS IN FY 2022

RPT will continue to provide testing of the RS-25 engines on the A-1 Test Stand in support of the Artemis Campaign. The B-2 Test Stand will be transitioned to facilitate a similar integrated upper stage test for the major elements of the Exploration Upper Stage (EUS) engine and plume management system. The Stennis Space Center (SSC) E-Complex test cells are to continue to support commercial customers and internal component level test requirements. At MSFC Test facilities, RPT plans to continue testing in support of advanced manufacturing development techniques through testing of engine components,

ROCKET PROPULSION TEST

including rocket nozzles. Testing is planned in evaluation of advance 3D printing technologies for liquid rocket engines in landers and on-orbit stages/spacecraft. A follow-on test campaign is also planned to demonstrate the use of Blue Origin's uncooled subscale nozzle extensions for the purpose of evaluating nozzle materials performance under hot-fire conditions. In support of the SLS Booster Obsolescence and Life Extension (BOLE) Program, tests will be conducted on a Solid Rocket Test Motor Vehicle (SRTMV) motor to evaluate both insulation and nozzle materials under higher pressures. At GRC-ATF, thermal vacuum testing for the Sierra Nevada Corporation is planned at the In-Space Propulsion Facility (ISPF) to test the Dream Chaser Cargo System (DCCS). Testing will include flight environments simulation: acoustic, vibration, Electromagnetic Interference/Electromagnetic Compatibility (EMI/EMC), thermal vacuum and shock separation. The fore mentioned, HELIX integrated instrument payload will undergo environmental thermal testing.

At WSTF, Boeing Space Test Program III (STP-III) R40b (modified Shuttle Primary Reaction Control System) thrusters are being acceptance tested in support of the United States Space Force (USSF). Also, in multi-year support of the USSF, Minuteman III Propulsion System Rocket Engine (PSRE) de-militarization is being conducted, disassembling, decontaminating and eliminating hazards for safe and environmentally friendly disposal. WSTF will continue to support the Orion ESA Service Module with delta qualification of the ESM Main Engine Assembly Series valve. Boeing CST-100 Service Module Reaction Control System Acceptance Testing is to be conducted. Altitude simulation static hot-fire testing of the Aerojet Rocketdyne Post Boost Propulsion System (PBPS) is also planned.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

RPT will continue to provide testing of the RS-25 engines on the A-1 Test Stand in support of the Artemis Campaign. The B-2 Test Stand is to continue to support readiness for the integrated upper stage test of the Exploration Upper Stage (EUS) engine. MSFC Test Facilities will continue to conduct advanced manufacturing developmental testing. WSTF will continue to provide support for the Orion ESA Service Model, the Boeing CST-100 Service Module, and Minuteman militarization. The RPT capabilities will continue to provide critical support to commercial partners to facilitate access to space and improve propulsion test technologies and processes.

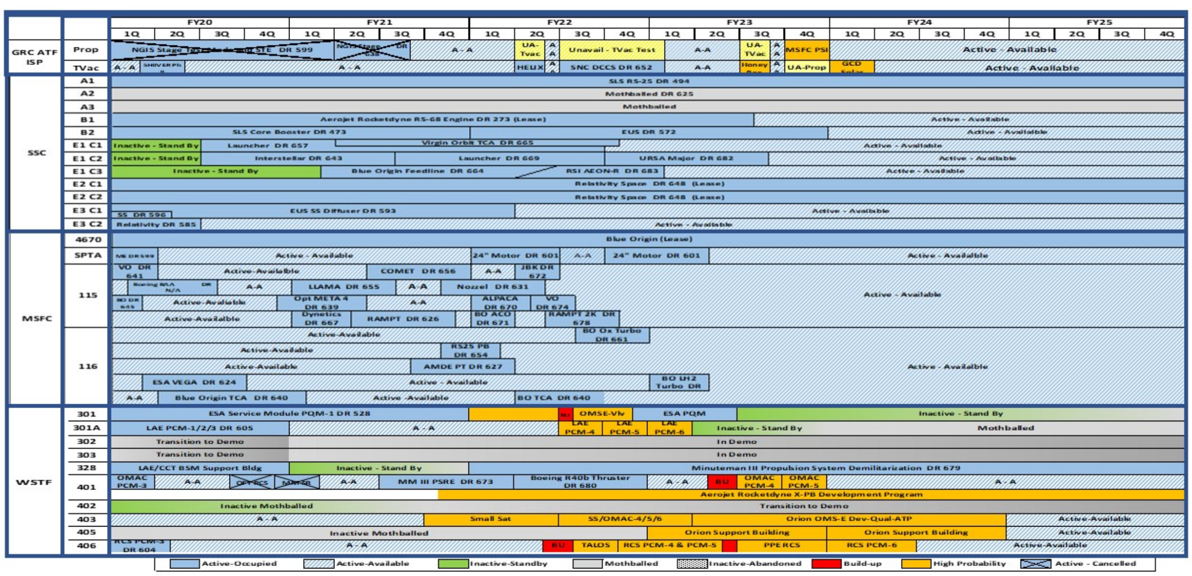
ROCKET PROPULSION TEST

Program Schedule

The following chart shows past, current, and planned test campaigns at SSC, MSFC, Glenn Research Center (GRC), and WSTF rocket propulsion test facilities. The designations at the far left of the chart refer to the facility, the top of the chart shows time by quarter of fiscal and calendar year, and the key to the status of each facility is at the bottom.

Most test stands and facilities are scheduled 18 months in advance. Defining the scope of work, selecting test stands and fuel, and estimating labor and total cost to customers is a complex process that can take 18 to 36 months. RPT is working now with internal and external customers to design testing programs for FY 2023 and beyond.

ROCKET PROPULSION TEST PROGRAM CONSOLIDATED TEST STAND UTILIZATION



PROGRAM MANAGEMENT & COMMITMENTS

Program Element	Provider
RPT	Provider: RPT Lead Center: N/A Performing Center(s): SSC, JSC, GRC, MSFC, KSC, WFF Cost Share Partner(s): Various other NASA programs, DoD, and commercial partners

ROCKET PROPULSION TEST

ACQUISITION STRATEGY

None.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

None.

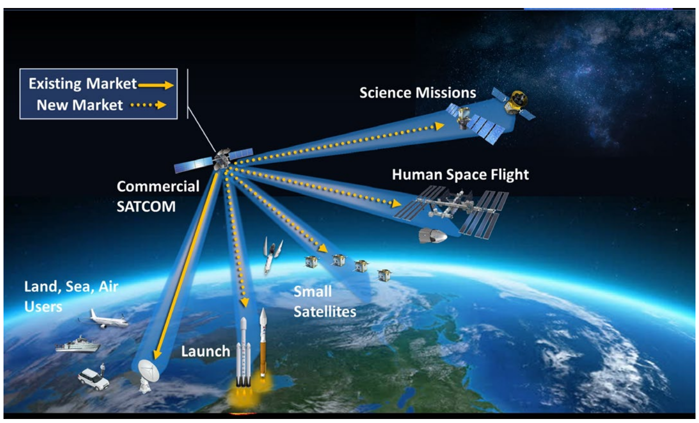
COMMUNICATIONS SERVICES PROGRAM

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	23.4	42.0	51.7	59.4	59.7	59.7	59.7
Change from FY 2022 Budget Request			9.7				
Percent change from FY 2022 Budget Request			23.1%				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



The Communications Services Program will collaborate with industry to demonstrate commercially-provided data relay services for NASA space missions.

The Communications Services Program (CSP) focuses on demonstrating the feasibility of commercially provided satellite communications (SATCOM) services to NASA missions. CSP is pursuing demonstrations that will allow future NASA missions to use flight-qualified commercial communications services. Ultimately, if CSP demonstrations are successful, near-Earth users will begin transitioning from using NASA-owned networks to commercially provided services.

The CSP effort is a component of the larger NASA strategy to migrate near-Earth missions from communications and navigation services provisioned by Government-owned networks to commercial networks. This transition to commercial services, and particularly commercial SATCOM, is driven by the state of current NASA network assets, by the National Space Policy, and by long-standing Federal procurement policies that direct the Government to make use of, rather than duplicate, commercially-provided services. NASA will not replenish the Tracking and Data Relay Satellites as aging spacecraft assets are decommissioned in the 2030's. NASA will continue to support existing users but seeks to transition future space-relay users to commercial providers. This approach is consistent with Federal policies intended to increase the cost-effectiveness of Government operations and leverage investments that have already been made by the private sector.

The SCaN program has overarching Agency responsibility to ensure that operational NASA missions receive required communications and navigation support. CSP retains the responsibility to execute demonstrations of commercial SATCOM services and provide assessments and recommendations for service acquisition to the Agency. SCaN will ensure that the transition to commercial services is managed in concert with the gradual phase out of the existing NASA-owned network resources.

COMMUNICATIONS SERVICES PROGRAM

NASA has a diverse set of users and communications needs against which commercial capabilities will be evaluated, such as launch vehicle support, visiting vehicles to the International Space Station, human space flight, and science missions in Earth orbit ranging from flagship observatories to SmallSats and CubeSats. CSP intends to leverage the SATCOM capabilities that have been developed for terrestrial users to bring the flexibility and functionality of commercial service to the space domain. CSP will work with the commercial market to identify requirements and explore opportunities that are mutually beneficial to NASA and industry. NASA expects to work with multiple commercial entities to demonstrate capabilities that best fulfill NASA's requirements, while also being compatible with a larger market where NASA can be one of many customers. These agreements will be designed to bolster American industry and reduce the cost of communication services to NASA, while promoting a diverse commercial market and maximizing interoperability between Government and commercial service providers.

CSP funding will support multiple agreements between NASA and commercial SATCOM companies to develop and demonstrate capabilities that can meet NASA's needs and begin the initial planning for acquisition of commercial SATCOM services.

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

ACHIEVEMENTS IN FY 2021

CSP has completed critical steps toward releasing the SATCOM service demonstrations announcement and solicitation. Activities included: a SCaN-hosted virtual industry event which rolled out the larger NASA commercialization strategy for near-Earth communications; Acquisition Strategy Meeting (ASM); and completion of the Formulation Authorization Document and the Project Strategy Briefing for Earth Relay Services Acquisition/Part One Demonstration.

CSP released the draft announcement and hosted a successful virtual Industry day on May 11, 2021 with over 140 participants, followed by two days of individual meetings with industry. CSP released the final solicitation on July 20, 2021 and final proposals were received on September 3, 2021.

WORK IN PROGRESS IN FY 2022

CSP plans to finish evaluating submitted proposals and make multiple demonstration awards in mid-FY 2022. NASA expects to demonstrate multiple capabilities through a diverse set of service providers over a multi-year period. Individual demonstration schedules will determine the overall period to complete all demonstrations. Capability demonstrations that are applicable for different classes of NASA missions and suitable for other customers are desirable. As such, the intent is to develop a demonstration portfolio of commercial capabilities that in the aggregate will address the future NASA mission needs for reliable, robust, and cost-effective communications and navigation services.

After demonstration contract awards and kickoffs, CSP will monitor the awardees' progress based on their execution and milestone plans and evaluate the success of the demonstrations based on technical, business, security, and operations attributes. CSP will engage with the mission community and stakeholders to review progress and results of the demonstrations.

CSP will complete a Formulation Systems Requirement Review (F-SRR), tailored from NASA engineering best practices. Individual demonstration reviews will be held according to industry best practices and individual milestones definitized in demonstration contracts.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

CSP will continue to monitor awardees' progress. CSP will initiate systems engineering trades and evaluate operational approaches for service management. Additional FY 2023 achievements, based on individual demonstration schedules, will be available after awards.

Program Schedule

The table below includes significant Communication Services Program milestones in FY 2022 and FY 2023.

Date	Significant Event
Q2 FY 2022	Demonstration Awards
TBD FY 2022	F-SRR
TBD FY 2022	Contract Milestones
TBD FY 2023	Contract Milestones

Program Management & Commitments

Program Element	Provider
Communications Services	Provider: CSP Project Office Lead Center: Glenn Research Center (GRC) Performing Center(s): N/A Cost Share Partner(s): N/A

Acquisition Strategy

In December 2020, CSP received, through the Acquisition Strategy Council, NASA concurrence to proceed with a funded Space Act Agreement acquisition approach for the demonstrations. NASA will define the future acquisition strategy for transitioning near-Earth NASA users to suitable commercially provided services, as informed by the demonstrations executed by CSP. This acquisition strategy could include commercial service contracts, hosted payloads, and/or public-private partnerships to obtain commercially provided satellite communications services.

COMMUNICATIONS SERVICES PROGRAM

MAJOR CONTRACTS/AWARDS

Awards are anticipated to be made in FY 2022. Details will be included in future justification documents.

INDEPENDENT REVIEWS

In FY 2022, CSP will complete a peer level F-SRR, tailored from NASA engineering best practices. Individual demonstration reviews will be held according to industry best practices and individual milestones definitized in demonstration contracts.

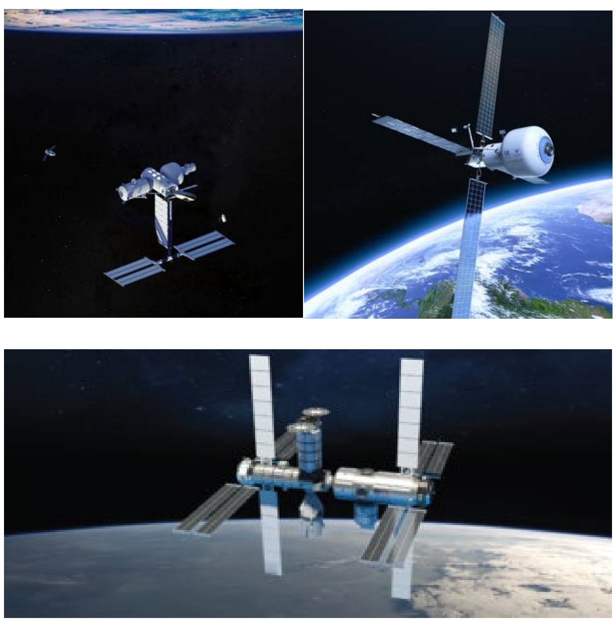
COMMERCIAL LEO DEVELOPMENT

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**18.1**	**102.6**	**224.3**	**228.2**	**229.4**	**302.1**	**435.0**
Change from FY 2022 Budget Request			**121.7**				
Percent change from FY 2022 Budget Request			**118.6%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



NASA is partnering with industry to develop and establish new commercial low-Earth orbit (LEO) destinations, culminating in NASA's participation as a customer in a robust space economy. NASA has signed agreements with three U.S. companies to develop designs of space stations and other commercial destinations in space. Top left: The Blue Origin and Sierra Space Orbital Reef baseline (Credits: Orbital Reef). Top right: Starlab, from Nanorack, Voyager Space, and Lockheed Martin (Credits: Nanorack / Lockheed Martin / Voyager Space). Bottom: Northrop Grumman's free flyer commercial destination (Credit: Northrop Grumman).

NASA seeks to maintain access to a low-Earth orbit (LEO) human-rated platform to continue the U.S. human presence – with both Government astronauts and private citizens – to support the utilization of space by U.S. citizens, companies, academia, and international partners, as well as to expand the American foothold in space. To successfully meet NASA's Strategic Goals and Objective 2.2 to "Develop a human spaceflight economy enabled by a commercial market," NASA established the Commercial LEO Development Program as a focused effort to ensure that there will always be a U.S. space station in low-Earth orbit that meets NASA's enduring requirements, even after the ISS is retired. In the course of meeting NASA's requirements, this program will also help develop a robust commercial space economy in LEO that supports good-paying jobs.

The Commercial LEO Development Program is building and executing a targeted strategy for an economy of space commerce" that is sustainable, cost-effective, and safe. The current strategy builds on and applies the lessons learned from over a decade of work and experiences with commercial companies.

NASA's Commercial LEO Development Program is supporting the development of commercially-owned and operated LEO destinations from which NASA, along with other customers, can purchase services that meet NASA's requirements and those of other users. As commercial LEO destinations (CLDs) become available, NASA intends to implement an orderly transition from current International Space Station (ISS) operations to these new CLDs. The transition of LEO operations to the private sector will yield efficiencies in the long term, enabling NASA to shift resources towards other objectives. With the introduction of CLDs, NASA expects to realize efficiencies from the use of smaller, more modern and efficient platforms, and a more commercial approach to meeting the Agency's needs in LEO. In the longer term, the gradual emergence of additional customers for commercial LEO destinations will offer the opportunity for additional savings.

To achieve the Commercial LEO Development Program's goals, NASA is committed to using the ISS and its capabilities to aid in the development of U.S. industry’s ability to provide the necessary platforms and services in LEO. NASA is also committed to continued Government utilization of LEO beyond the ISS for basic research and development, Earth and deep space observations, and astronaut training. NASA will support development of both the supply side of the future LEO economy (i.e., future platforms providing services for a fee) through the Commercial LEO Development budget and the demand side (i.e., users of on-orbit services) through the ISS Program budget. NASA is drafting a Service Requirements Document (SRD) that will define NASA’s needs for CLD services after ISS end of life. NASA's commitment to growing the future LEO economy also includes providing Government funding to private industry in the form of contracts and partnerships to ensure that future capabilities can fulfill Government requirements.

NASA is pursuing several avenues to enable the supply side of the LEO economy. These include offering the use of an ISS berthing port to a private company to deploy a new commercial element on the ISS, Commercial Destinations for ISS (CDISS); supporting the development and use of Commercial Destinations Free Flyers (CDFF); and offering the use of the ISS for private astronaut missions. A private astronaut mission is a commercial mission consisting of activities conducted by private astronauts aboard the ISS or in a commercial element attached to the ISS, transported on a U.S. commercial spacecraft dedicated to this private mission. NASA is enabling up to two short-duration private astronaut missions per year to the ISS. NASA’s expectation is that one or more of these development and demonstration efforts will prove commercially viable, allowing United States and international customers to purchase services in LEO while also providing NASA with the platforms and capabilities it requires in LEO.

For the ISS to support CDISS, NASA will reconfigure the ISS port, provide new ISS utilities and resources to the port, integrate the commercial elements onto ISS, and recertify new docking port locations for Commercial Resupply Services and Commercial Crew Program vehicles. These activities to support CDISS will be funded by the Commercial LEO Development Program.

NASA has also made the ISS available to private entities to enable commercial and marketing opportunities on the microgravity laboratory. Since making these opportunities available, there has been a growing demand for commercial and marketing activities from both traditional aerospace companies and from novel industries, demonstrating the benefits of the space station to help catalyze and expand space exploration markets and the low-Earth orbit economy. As a result, NASA has updated its pricing policy for commercial activities conducted on the station to reflect full reimbursement for the value of NASA resources.

NASA's Commercial LEO Development Budget supports and will advance the Nation’s goals in LEO and for deep space exploration by furthering the development and maturity of the commercial space market. This development will enable private industry to assume roles that have been traditionally Government-only by creating new opportunities for economic growth through new markets and industries in LEO and potentially yielding long-term cost savings to the Government by leveraging industry innovation and commercial market incentives.

Commercial LEO Development

Explanation of Major Changes in FY 2023

None.

Achievements in FY 2021

Continuing work that began in FY 2020, the commercial segment provider, Axiom Space Inc., completed their Preliminary Design Review (PDR) for the Axiom Hub Hab One and Two (AxH1 and AxH2), and their System Requirements Review (SRR) for the third planned Axiom Segment module, the Axiom Research and Manufacturing Facility (AxRMF), their Robotic Arm (AxARM), their Earth Observatory (AxEO) (similar to the ISS Cupola) and Docking Adapter (to enable later commercial vehicles to dock to the Axiom Segment). Axiom also completed initial forgings associated with primary structure of AxH1 and AxH2 and performed early development tests to mature design/requirements including early Avionics/Software, Power Storage, Guidance Navigation and Control, Propulsion, and internal configuration.

Equally critical to enabling the supply side of the LEO economy, NASA finalized the acquisition strategy to enable partnerships for the development and space flight demonstrations of free-flying commercial LEO destinations. NASA sought commercial LEO destinations that would provide a diverse portfolio of products and services that meet both NASA and non-NASA needs. An Acquisition Strategy Council (ASC) was held on March 12, 2021, which approved a two phased acquisition strategy for CLDs. Phase 1, CDFF, will utilize multiple funded Space Act Agreements. Phase 1 is expected to last approximately four years and will culminate in at least a preliminary design level of maturity. In the second phase, NASA intends to certify commercial LEO destinations and purchase destination services when such services become available for purchase.

NASA established a commercial use and pricing policy for the ISS, enabling companies to reduce uncertainty and build business plans as they seek to perform commercial activities, including marketing. NASA completed clarifying updates to this policy associated with commercial activities, including addressing the procurement of services for private astronaut mission providers. NASA also finalized private astronaut mission framework, requirements, and concept of operations.

Work in Progress in FY 2022

Axiom will continue the development of the commercial segment that will attach to the ISS (CDISS), including maturing the preliminary design, which will be reviewed at the AxH1 and AxH2 Design Progress Review, and initiating the Critical Design Review (CDR) for the first two commercial elements, Axiom Hab One and Two (AxH1 and AxH2). The primary structure for AxH1 and AxH2 is undergoing initial machining operations. Axiom is also continuing development tests of hardware to support the flight hardware procurement and build. Axiom has initiated construction for a large manufacturing and assembly facility to be used to prepare flight hardware prior to launch. In addition, Axiom will continue to mature hazard reports and verification concepts to ensure successful and compliant integration with ISS.

NASA is also planning for the first private astronaut mission with Axiom aboard ISS to take place no earlier than March 2022. The Axiom private astronauts are scheduled to spend eight days aboard ISS. Axiom will purchase services for the mission from NASA, such as crew supplies, cargo delivery to space, storage, and other in-orbit resources for daily use. NASA will purchase from Axiom the capability to return scientific samples that must be kept cold in transit back to Earth.

COMMERCIAL LEO DEVELOPMENT

On December 13, 2021, NASA selected Axiom Space for the second private astronaut mission to the ISS. NASA will negotiate with Axiom on a mission order agreement for the Axiom Mission 2 (Ax-2) targeted to launch between fall 2022 and late spring 2023.

On December 2, 2021, NASA awarded SAAs to three U.S. companies to develop designs of space stations and other commercial destinations in space. The agreements are part of the Agency's efforts to enable a robust, American-led commercial economy in low-Earth orbit. The total estimated award amount for all three funded Space Act Agreements is $415.6 million. The companies that received awards are:

- Blue Origin of Kent, Washington, for $130 million;
- Nanoracks LLC of Houston, Texas, for $160 million; and
- Northrop Grumman Systems Corporation of Dulles, Virginia, for $125.6 million.

As mentioned above, the awards are the first in a two-phase approach to ensure a seamless transition of activity from the International Space Station to commercial destinations. During this first phase, private industry, in coordination with NASA, will formulate and design commercial low-Earth orbit destination capabilities suitable for potential Government and private sector needs. The first phase is expected to continue through 2025.

Blue Origin and Sierra Space have partnered to develop Orbital Reef, a commercially owned and operated space station to be built in low-Earth orbit, which will start operating in the second half of this decade. Orbital Reef teammates include Boeing, Redwire Space, Genesis Engineering, and Arizona State University. Orbital Reef's human-centered space architecture is designed to be a "mixed-use space business park" that provides essential infrastructure needed to support all types of human spaceflight activity in low-Earth orbit and can be scaled to serve new markets. Blue Origin is scheduled to complete four milestones in FY 2022 including their SRR and System Definition Review (SDR).

Nanoracks' commercial low-Earth orbit destination, in collaboration with Voyager Space and Lockheed Martin, is called "Starlab." Starlab is targeted for launch in 2027 on a single flight as a continuously crewed, commercial space station dedicated to conducting advanced research, fostering commercial industrial activity, and ensuring continued U.S. presence and leadership in low-Earth orbit. Starlab is designed for four astronauts and will have power, volume, and a payload capability equivalent to the ISS. Nanorack is scheduled to complete three milestones in FY 2022 including their spacecraft SRR and SDR.

Northrop Grumman's design for a modular, commercial destination in low-Earth orbit is built on decades of experience supporting NASA, defense, and commercial programs. The design leverages flight-proven elements, such as the Cygnus spacecraft that provides cargo delivery to ISS, to provide a base module for extended capabilities including science, tourism, industrial experimentation, and the building of infrastructure beyond initial design. Northrop Grumman is scheduled to complete three milestones in FY 2022 including their Concept of Operations (ConOps) review.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

NASA will also develop an overall commercial LEO destinations human-rating strategy as well as requirements.

Axiom plans to continue development of their proposed commercial elements, including the completion of the CDR for the first two commercial elements, Axiom Hab One and Two (AxH1 and AxH2), in addition to the completion of the PDR for the AxRMF, AxEO and AxARM. Additionally, Axiom is planning to complete the hazard report development associated with the Phase 3 review of the NASA

Safety Review Process associated with AxH1 and AxH2. Axiom plans to complete construction for their manufacturing and assembly facility and to receive early flight hardware to support integration and verification activities. Axiom also plans to accept delivery of the finished primary structural assembly from their vendor to start final assembly, outfitting and verification of their first module, AxHab 1. Axiom is currently planning to launch the first element to ISS in late 2024.

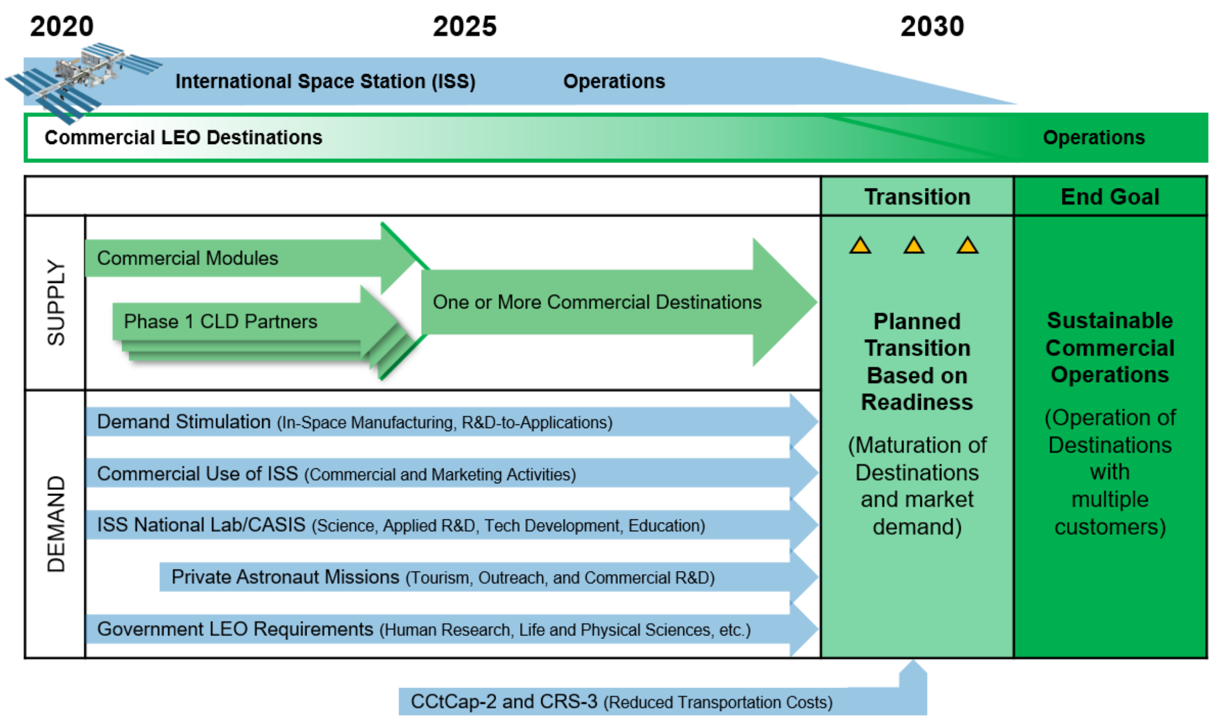
Blue Origin is scheduled to complete four milestones in FY 2023 including their Core Structural Test and Full-scale Burst Test.

Nanoracks is scheduled to complete four milestones in FY 2023 including their Spacecraft PDR.

Northrop Grumman is scheduled to complete seven milestones in FY 2023 including their CDFF level SRR and SDR, Element 1 level SRR and SDR, Module level SRR, and Initial Habitation Demonstration.

Program Schedule

The following chart depicts the near-term roadmap of planned Commercial LEO Development efforts.



COMMERCIAL LEO DEVELOPMENT

Program Management & Commitments

Program Element	Provider
Commercial LEO Development Program	Providers: Axiom Space, Inc.; Blue Origin; Nanoracks; Northrop Grumman Systems Corporation Lead Center: Johnson Space Center (JSC) Performing Center(s): JSC Cost Share Partner(s): Industry Partners (shown above)

Acquisition Strategy

NASA uses multiple acquisition tools for Commercial LEO Development. The established Next Space Technologies for Exploration Partnerships (NextSTEP-2) Broad Agency Announcement (BAA) contract vehicle was used for the Commercial Destinations for ISS contract to initiate development of the commercial segment. Similar to the approach used for the Commercial Orbital Transportation System (COTS) and Commercial Crew, NASA is using Space Act Agreements for Phase 1 of the CDFF. FAR-based contracts will be utilized for CDFF Phase 2 to perform certification activities and purchase destination services.

Major Contracts/Awards

Element	Vendor	Location (of work performance)
Commercial Destination for International Space Station (CDISS)	Axiom Space, Inc.	Houston, TX
Commercial Destinations Free Flyers (CDFF)	Blue Origin	Kent, WA
Commercial Destinations Free Flyers (CDFF)	Nanoracks LLC	Houston, TX
Commercial Destinations Free Flyers (CDFF)	Northrop Grumman Systems Corporation	Dulles, VI

Independent Reviews

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	NASA Advisory Council	Jan 2022	Provide independent guidance for the NASA Administrator	The panel provided no new formal recommendations or findings for the Commercial LEO Development Program	Mar 2022

COMMERCIAL LEO DEVELOPMENT

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Other	NASA Aerospace Safety Advisory Panel	Jan 2022	Provides independent assessments of safety to the NASA Administrator	The panel provided no new formal recommendations or findings for the Commercial LEO Development Program.	TBD

EXPLORATION OPERATIONS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Orion Production & Sustainment	0.0	0.0	**TBD**	786.9	925.3	990.2	1,022.5
Exploration Operations Program	0.0	0.0	**TBD**	46.0	47.0	47.0	48.0
Total Budget	**0.0**	**0.0**	**TBD**	**832.9**	**972.3**	**1,037.2**	**1,070.5**

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The FY 2023 President's budget request for NASA includes authority to transfer funds in FY 2023 from Orion Multi-purpose Crew Vehicle to Exploration Operations for Orion Production and Operations, up to $718 million, contingent on assessments following Artemis I.

The overall integrated Artemis Plan and the Agency's human spaceflight reorganization approved in 2022 assign responsibility for development of exploration hardware to the Exploration Systems Development Mission Directorate (ESDMD). Post-development production and mission operations are the responsibilities of the Space Operations Mission Directorate (SOMD). The FY 2023 Budget creates the Exploration Operations theme within the Space Operations account to fund these capabilities developed by ESDMD and handed off to SOMD for production and operations. As various Artemis missions complete their initial development and production of hardware and/or capability and demonstrate their ability to move into production and sustainment mode, funding for these programs will be provided in the Exploration Operations theme. Initially, there are two programs planned under this theme: Orion Production and Sustainment, and Exploration Operations. Other Artemis campaigns, including, Space Launch System, Exploration Ground Systems, Human Landing Systems and Gateway, will transition in future Budgets.

The first program to transition, Orion, will start this process beginning in FY 2022, as provided for in the Consolidated Appropriations Act, FY 2022. A full transition of program management and execution will take place after the completion of the Artemis II mission and the final development of the Rendezvous, Proximity Operations and Docking capability for Artemis III. The transition of Orion, and transitions of other programs in the future, is tied to scope, rather than a specific point in time. Transitioning by scope allows the clearest way to track work tied to milestones.

EXPLORATION OPERATIONS

ORION TRANSITION TO OPERATIONS

In FY 2023 through FY 2027, the Orion Program will complete development and transition to a production and sustainment phase. In accordance with reorganization implemented in FY 2022, development activity will continue to be funded in the DSES account (managed by ESDMD) and production, sustainment, and operations will be funded in the Space Operations account (managed by SOMD). Per the Orion Program's Agency Baseline Commitment, development will end with the Artemis II mission, though DSES will continue to fund follow-on development activities such as RPOD and the Orion Main Engine (OME). For Artemis III and out, the Orion Program will use Space Operations funding to deliver Orion spacecraft.

The long lead times associated with producing an Orion spacecraft require the Orion Program to initiate production activity multiple years in advance. Under the FY 2023 Budget, NASA anticipates that the Orion Program will fund some level of production on the vehicles for Artemis II, Artemis III, Artemis IV, and Artemis V simultaneously. NASA will fund the Orion Program out of both the Development Space Exploration System (DSES) and Space Operations accounts in this period, consistent with the description above. Note, however, that there still will be one Orion Program Manager and no contract changes or organizational changes will be required for the prime contractor.

In FY 2023, NASA will still be completing development of the Artemis II spacecraft. To provide the Program with flexibility in determining the FY 2023 allocation between the two accounts, this Budget assumes the full Orion Program budget will be appropriated in the DSES account. The budget also proposes an Administrative Provision (see below) enabling NASA to determine the requisite split after FY 2023 appropriations. The Orion Program is unlikely to need such flexibility in FY 2024 and beyond, as Orion development will be nearly complete.

"Of the amounts provided for Orion Multi-purpose Crew Vehicle, up to $718 million may be transferred to Space Operations for Orion Production and Operations consistent with direction provided in the explanatory statement accompanying this Act. The authority provided by this paragraph is in addition to the authority provided by the second paragraph under this heading."

Exploration Operations Program will support mission operations content for the Artemis missions. The goal is to provide integration for exploration operations fully coordinated with the mission integration and engineering support from Common ESD and Artemis Campaign Development programs. Tasks of the Exploration Operations Program include, but are not limited to mission management, training of flight controllers, and crews; and command, control, track, and monitor crewed systems and navigation during flight operations.

NASA will also begin to fund mission operations preparation and activity for Orion in the Exploration Operations Program.

EXPLORATION OPERATIONS

The full budget for the Orion Program is as follows:

(in $ millions)	FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Integration and Support	15.9	17.9	13.4	-	-	-	-
Development	1,387.8	1,388.8	1,325.3	415.0	116.5	52	19
Orion Exploration Total	**1,403.7**	**1,406.7**	**1,338.7**	**415.0**	**116.5**	**52.0**	**19.0**
Production and Sustainment	-	-	TBD	786.9	925.3	990.2	1,022.5
Operations	-	-	TBD	46.0	47.0	47.0	48.0
Orion Space Ops Total	**-**	**-**	**-**	**832.9**	**972.3**	**1,037.2**	**1,070.5**
Orion Program Total	**1,403.7**	**1,406.7**	**1,338.7**	**1,247.9**	**1,088.8**	**1,089.2**	**1,089.5**

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The FY 2023 President's budget request for NASA includes authority to transfer funds in FY 2023 from Orion Multi-purpose Crew Vehicle to Exploration Operations for Orion Production and Operations, up to $718 million, contingent on assessments following Artemis I.

ORION PRODUCTION & SUSTAINMENT

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	0.0	0.0	TBD	786.9	925.3	990.2	1,022.5

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

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The FY 2023 President's budget request for NASA includes authority to transfer funds in FY 2023 from Orion Multi-purpose Crew Vehicle to Exploration Operations for Orion Production and Operations, up to $718 million, contingent on assessments following Artemis I.

Artemis III Crew Module (CM) lifted out of the "bird cage" at Kennedy Space Center (KSC).

Top view of the Artemis IV CM pressure vessel forward bulkhead at Michoud Assembly Facility (MAF).

In keeping with the overall integrated Artemis Plan and the Agency's human spaceflight reorganization approved in 2022, the Orion Production and Sustainment program was created within the Exploration Operations theme to fund these capabilities in the Space Operations appropriation. As the Orion Program completes the initial development and production of hardware and demonstrates the ability to move into production and sustainment in FY 2024, funding will be provided in this budget line.

Orion will undergo the transition of those activities beginning in FY 2022, using transfer authority in FY 2022 and FY 2023, with the transfer of program management and execution taking place after the completion of the Artemis II mission and the final development of the Rendezvous, Proximity Operations and Docking (RPOD) capability for Artemis III.

ORION PRODUCTION & SUSTAINMENT

EXPLANATION OF MAJOR CHANGES IN FY 2023

Funding to support Orion production and operations beginning with the Artemis III flight that was previously budgeted in the theme previously named Exploration Systems Development (ESD) has been transferred to this theme. It also allows the program to fund long-lead procurements for future Artemis missions that are a part of the Orion Production and Operations Contract (OPOC).

ACHIEVEMENTS IN FY 2021

The Artemis III Crew Module Adapter (CMA) inner wall was delivered to Kennedy Space Center (KSC) in May 2021. The inner wall, together with pressure vessel and heatshield are the primary structure build-up and assembly of the Crew Module (CM) and CMA.

Orion held a successful Artemis III docking system Critical Design Review (CDR) in April 2021. This review assessed the readiness of the docking system design to progress to full-scale fabrication, assembly, integration, and test.

WORK IN PROGRESS IN FY 2022

Eight European Service Module-3 (ESM) auxiliary engines were shipped to the European Space Agency (ESA) prime contractor's facility in Bremen, Germany - six in October 2021 and the last two in December 2021. The Artemis III pressure vessel was delivered to KSC in October 2021. Further build-up of the CM structure is underway, including installation of the CM interface brackets and forward gussets. Proof pressure and leak testing of the CM pressure vessel was completed in February 2022, the CM is now being de-configured from the test configuration, followed by several months of internal and external systems hardware installations, including secondary structures, active components, harnesses, tubing, and tube welding.

The Artemis III CMA aft walls are being installed at KSC with forward and outboard walls which were delivered in January 2022. Installation of the CMA longerons, which are load-bearing structural components, is currently underway. Assembly, integration, and processing of the Artemis III CMA will be performed throughout the fiscal year, with planned completion in September 2022.

The Artemis III heatshield carrier will be delivered to KSC in April 2022 for Avcoat installation, which will continue into FY 2023. Avcoat is the ablative heat shield that protects the crew during high-speed reentry into Earth's atmosphere.

A large volume of Artemis III components has been delivered over the course of the first two quarters of FY 2022 in support of the Artemis III CM and CMA subassembly installation schedules.

Orion will begin Artemis IV pressure vessel fabrication at Michoud Assembly Facility (MAF) in FY 2022 with the plan to deliver it to KSC in Q2 of FY 2023.

The program will conduct the Preliminary Mission Integration Review (MIR) for Artemis V and will initiate contract authorization for Artemis VI-VIII in FY 2022.

ORION PRODUCTION & SUSTAINMENT

KEY ACHIEVEMENTS PLANNED FOR FY 2023

Artemis III CM assembly, integration, and testing will continue in FY 2023, with CM readiness to mate to the Service Module (SM) planned for July 2023.

Delivery of the ESM-3 to KSC is planned for no earlier than (NET) February 2023. The Artemis III ESM and CMA will be mated to form the SM and will undergo final installation and testing for the following few months. The SM will be ready to mate with the CM NET October 2023, to form the Artemis III CSM.

Throughout FY 2023, several key functional components of the RPOD system will be delivered, as well as the initial release of RPOD software, to support the planned Initial Power On testing of the CM in the O&C for Artemis III. The RPOD system enables critical rendezvous, proximity operations, docking, as well as undocking operations that will begin with the Artemis III mission. A key high fidelity, Six-Degree-of-Freedom Test System of the RPOD system, complete with docking cameras and sensors, will be conducted at a Lockheed Martin facility in Denver, CO. These tests will demonstrate the safety-critical operation of the RPOD hardware and software in the dynamic proximity operations environment.

Following delivery of the Artemis IV pressure vessel and primary structure parts to KSC, Orion will continue with structural assembly, proof test, and subsystem installations on the CM throughout FY 2023.

In August 2023, Orion will conduct a Preliminary MIR for Artemis IV docking system components.

The Artemis IV pressure vessel will be delivered to KSC in the second quarter of FY 2023.

Program Elements

CREW MODULE

The crew module provides a safe habitat for the crew, as well as storage for consumables and research instruments, and it serves as the docking port for crew transfers.

SERVICE MODULE

The service module fuels and propels the Orion spacecraft, will support the Crew Module from launch through separation before reentry.

LAUNCH ABORT SYSTEM

The launch abort system maneuvers the Crew Module to safety in the event of an emergency during launch or climb to orbit.

ORION PRODUCTION & SUSTAINMENT

Program Management & Commitments

Program Element	Provider
Crew Module	Provider: Johnson Space Center (JSC) Lead Center: JSC Performing Center(s): Ames Research Center (ARC), Glenn Research Center (GRC), JSC, Kenney Space Center (KSC) Langley Research Center (LaRC) and Michoud Assembly Facility Cost Share Partner(s): N/A
Service Module	Provider: JSC Lead Center: JSC Performing Center(s): Ames Research Center (ARC), Glenn Research Center (GRC), JSC, KSC and LaRC Cost Share Partner(s): N/A
Launch Abort System	Provider: JSC Lead Center: JSC Performing Center(s): Ames Research Center (ARC), Glenn Research Center (GRC), JSC, KSC and LaRC Cost Share Partner(s): N/A

Acquisition Strategy

Orion Program released a Request for Proposal (RFP) to Lockheed Martin for the production and operations effort in January 2018. OPOC was awarded as a sole-source contract with Lockheed Martin in September 2019 and will begin with Artemis III. It is an indefinite-delivery-indefinite-quantity contract that includes a commitment to order a minimum of six and a maximum of 12 Orion spacecraft over the next 10 years. The first six spacecraft (Artemis III through VIII) will be acquired by cost-plus-incentive-fee orders. NASA will negotiate firm-fixed-price orders for future missions to take advantage of the anticipated spacecraft production cost decreases.

Consistent with Annex 3 of NASA's 2012 Implementing Arrangement with ESA, ESA on May 26, 2020 signed a contract with Airbus to build ESM-3 for Artemis III. In October 2020, NASA and ESA signed the Gateway Memorandum of Understanding, in which ESA agreed to provide two additional ESMs to NASA. This was followed in February 2021 by ESA signing a contract with Airbus to build three additional ESMs in support of Artemis IV through VI. NASA and ESA are currently working on an Implementing Arrangement for the details of the provision of ESM-4 and ESM-5. A signed agreement is anticipated by April 2022.

Orion published an RFP for the Orion Main Engine (OME) engines in March 2020, which will replace the Orbital Maneuvering System Engine (OMS-E) starting with Artemis VII. The contract was awarded in September 2021. Orion has enough OMS engines remaining from the Space Shuttle Program to fly on the ESM through Artemis VI.

ORION PRODUCTION & SUSTAINMENT

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Orion Production and Operations Contract (OPOC)	Lockheed Martin	Littleton, CO
Orion Main Engine (OME)	Aerojet Rocketdyne, Inc	Los Angeles, CA & Redmond, WA

EXPLORATION OPERATIONS PROGRAM

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**0.0**	**0.0**	**TBD**	**46.0**	**47.0**	**47.0**	**48.0**

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

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The FY 2023 President's budget request for NASA includes authority to transfer funds in FY 2023 from Orion Multi-purpose Crew Vehicle to Exploration Operations for Orion Production and Operations, up to $718 million, contingent on assessments following Artemis I.

Exploration Operations Program will initially support mission operations content for the Artemis missions. The goal is to provide integration for exploration operations fully coordinated with the mission integration and engineering support from Common Exploration Systems Development and Artemis Campaign Development programs. These include, but are not limited to mission management, training of flight controllers and crews; and command, control, track, and monitor crewed systems and navigation during flight operations.

EXPLANATION OF MAJOR CHANGES IN FY 2023

Beginning in FY 2023, the Orion Program began transitioning from a development program within the Deep Space Exploration Systems account, to an operational program within the Space Operations account. Some of the content that was previously funded in Deep Space Exploration Systems for Orion to support crew operations will be transitioned to this new program being established at Johnson Space Center (JSC). Due to manifest changes for Artemis I, FY 2023 funding is included in the development program and the specific amounts for operations will be transferred in the Initial Operating Plans for each fiscal year.

ACHIEVEMENTS IN FY 2021

N/A.

WORK IN PROGRESS IN FY 2022

The NASA JSC is undertaking organizational changes to establish a new Exploration Operations Program Office. The goal is to provide mission management integration for exploration crewed operations within the Space Operations Mission Directorate (SOMD). SOMD will fully coordinate with the Exploration Systems Development Mission Directorate (ESDMD) mission integration and engineering support. JSC is establishing the program office with the Program Manager reporting through the newly created Exploration Operations Division to SOMD.

NASA is combining management of the following functions to support Artemis crewed flights, all of which are already assigned to JSC, into a single organization to facilitate technical and programmatic efficiency and effectiveness: mission integration, ground rules, requirements, consumables, logistics/cargo, and payload integration. Additional functions that may be transitioned are under review.

A Program Management Plan is being developed during 2022 in conjunction with the establishment of the program office. All program elements are envisioned to have JSC as the lead center.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

Continue mission management activities in support of Artemis crewed flights beginning with the Artemis III after they are transitioned from the Orion program.

SPACE TECHNOLOGY

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Early Stage Innovation and Partnerships	117.5	145.0	**155.9**	159.5	162.7	169.9	188.2
Technology Maturation	227.1	491.2	**471.6**	481.1	491.2	497.6	493.1
Technology Demonstration	528.4	501.8	**525.4**	535.4	545.6	556.0	566.6
SBIR and STTR	227.0	287.0	**285.0**	290.7	296.5	302.4	308.5
Total Budget	**1,100.0**	**1,425.0**	**1,437.9**	**1,466.7**	**1,496.0**	**1,525.9**	**1,556.4**

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Pursuant to P.L. 115-10 Title VII Sec 702(e), this budget is formulated in such a manner to avoid duplication of projects, programs, or missions conducted by other projects, programs, or missions conducted by another office or directorate of the Administration.

SPACE TECHNOLOGY

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Early Stage Innovation and Partnerships	117.5	145.0	**155.9**	159.5	162.7	169.9	188.2
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SBIR and STTR	227.0	287.0	**285.0**	290.7	296.5	302.4	308.5
Total Budget	**1,100.0**	**1,425.0**	**1,437.9**	**1,466.7**	**1,496.0**	**1,525.9**	**1,556.4**
Change from FY 2022 Budget Request			**12.9**				
Percent change from FY 2022 Budget Request			**0.9%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Pursuant to P.L. 115-10 Title VII Sec 702(e), this budget is formulated in such a manner to avoid duplication of projects, programs, or missions conducted by other projects, programs, or missions conducted by another office or directorate of the Administration.

The Low-Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID) is a partnership between NASA's Space Technology Mission Directorate and the United Launch Alliance (ULA) and is poised to revolutionize the way NASA and industry deliver payloads to a planet's surface or into orbit, utilizing aerodynamic forces instead of propulsion. LOFTID is scheduled to launch from Vandenberg Air Force Base in late 2022. This image shows LOFTID inflated in Building 1250 at LaRC.

The Space Technology Mission Directorate (STMD) is dedicated to developing transformative, crosscutting technologies that enhance the capabilities and reduce the cost of NASA, commercial, and other Government missions. Through STMD, NASA invests in high-risk, high-reward activities across the technology development spectrum in collaboration with the Nation's aerospace industry, academia, and small and large businesses. These technology investments support and stimulate a robust space economy.

Space Technology investments keep NASA's technology pipeline growing with emerging, innovative technologies that benefit a wide range of users, ensuring the Nation realizes the full economic value and societal benefit of these innovations. STMD's technology portfolio includes broad technology applications addressing multiple stakeholder needs and actively engages them to identify opportunities of common interest to better leverage Government investments. The Industry and Commerce Innovative Opportunity will foster commercial markets through collaboration by investing in industry-developed space technologies that can advance the commercial space sector and benefit future NASA missions. And, finally, NASA is actively promoting one of the Administration's priorities by encouraging diversity both within the Agency and the larger aerospace community. STMD promotes innovation within underserved communities by increasing program participation from women and socially or economically disadvantaged businesses, historically black colleges and universities (HBCU), and minority serving institutions (MSI) in its programs. NASA utilizes extensive university research, science, and technology expertise to advance the Agency's missions, while furthering the career development of the Nation's next generation of scientists, technologists, and explorers. STMD has over 500 different academic partners supporting research and technology projects that foster greater interest in STEM careers and support technological advancement and economic growth.

STMD continues to leverage and diversify its industry partners, creating new ways of engaging and working with the commercial space industry as a potential user and not just a provider of new technologies; thereby, enabling and enhancing NASA and commercial mission needs through innovation and job creation. Additionally, STMD continues to seek recommendations from the National Academies' Space Technology Industry-Government-University Roundtable (STIGUR) and the NASA Advisory Council's (NAC) Technology, Innovation, and Engineering (TI&E) Committee, and fosters partnerships and collaborations by routinely engaging industry and academia through venues such as the Lunar Surface Innovation Consortium (LSIC), conferences, and symposiums.

EXPLANATION OF MAJOR CHANGES IN FY 2023

Compared to the FY 2022 President's Budget Request, the FY 2023 funding request includes $5 million to initiate the On-orbit Servicing, Assembly and Manufacturing (OSAM) Consortium consisting of Government departments and agencies, universities, non-profit research institutions, NASA centers and mission directorates, and commercial companies. Additionally, this budget provides $15 million for nuclear propulsion.

RECENT ACHIEVEMENTS

In FY 2021, Space Technology's programs contributed to the development of transformative space technologies primarily intended to enable NASA's future robotics, science, and human exploration missions. NASA's investments in space technology advanced capabilities for science and exploration and initiated new prize competitions and partnerships that helped solve complex challenges needed to fulfill the Agency's goals in space.

EARLY STAGE INNOVATIONS AND PARTNERSHIPS

Space Technology Research Grants

- The Space Technology Research Grants (STRG) Program continued to challenge the spectrum of academic researchers to examine the theoretical feasibility of ideas and approaches that are critical to making science, space travel, and exploration more effective, affordable, and sustainable. In FY 2021, NASA made 14 Early Stage Innovation awards, six Lunar Surface Technology Research (LuSTR) awards, six Early Career Faculty awards, and 58 NASA Space Technology Graduate Research Opportunity awards.

NASA Innovative Advanced Concepts (NIAC)

- NIAC continued to "Change the Possible" in aerospace and aeronautics missions by investing in early innovative and visionary concept studies. NIAC nurtured visionary ideas that could transform future NASA missions with the creation of breakthroughs, while engaging America's innovators and entrepreneurs as partners in the journey. In FY 2021, NIAC made 23 awards (16 Phase I, six Phase II, and one Phase III) covering a wide range of disciplines and missions. The awards reflected an influx of new innovative aerospace concepts where 45.9 percent were new proposals and an increase in diversity where NIAC solicitations are attracting and engaging more female awardees.

Prizes, Challenges and Crowdsourcing (PCC)

- The Prizes, Challenges, and Crowdsourcing (PCC) Program, which conducted and promoted the use of prize competitions and crowdsourcing as tools to advance NASA research and development, awarded a total of $3.6 million in cash prizes for FY 2021 and managed 65 active projects to advance NASA's mission and enhance connections with the public through open innovation tools and approaches. PCC received 25,775 solutions through the National Tournament Lab public-facing challenges, crowdsourcing platform using the internal NASA@WORK, and Centennial Challenges. PCC is also expanding its digital reach, has 334,000 followers, and is engaging people from across 100 countries and all 50 states.

Technology Transfer

- The NASA Technology Transfer (T2) Program executed 211 licensing agreements for technologies and software, the most the program has ever achieved in a fiscal year. NASA signed 5,184 Software Usage Agreements. This success can be directly attributed to streamlining and automating processes like licensing applications to create a more "customer-friendly" approach to working with the Federal Government. Also, in FY 2021, T2 held a total of 130 virtual in-reach events, which reached more than 7,400 innovators.

TECHNOLOGY MATURATION (GAME CHANGING DEVELOPMENT [GCD] PROGRAM AND LUNAR SURFACE INNOVATION INITIATIVE [LSII])

- Since its inception in 2019, the Lunar Surface Innovation Initiative (LSII) has engaged over 400 organizations across 48 states and Puerto Rico to advance the technologies needed to explore the lunar surface and stimulate economic development.
- The Safe & Precise Landing Integrated Capabilities Evolution (SPLICE) project is a suite of precision landing and hazard-avoidance technologies. Three of SPLICE's four main subsystems had their first integrated test flight on a Blue Origin New Shepard rocket on October 13, 2020. Engineers used data to make slight adjustments to the navigation system before the second flight aboard Blue Origin's New Shepard rocket, which occurred on August 26, 2021.
- In September 2021, NASA awarded contracts to five companies to mature vertically deployable solar array systems for the lunar surface under the Vertical Solar Array Technology (VSAT) project, which aims to support NASA's long-term lunar surface operations. All five companies – Astrobotic, Honeybee Robotics, Maxar, Northrop Grumman, and Lockheed Martin – are designing prototype systems of highly-reliable power sources using tall, vertically-structured solar arrays that will help prevent loss of power at the lunar poles where the Sun does not rise very far above the horizon.

- The BIG Idea Challenge, a unique collaboration between STMD GCD and the Office of STEM Engagement (Space Grant Consortium), now in its seventh year, invites university students to tackle some of the most critical needs facing space exploration and the mission capabilities that could make new discoveries possible. The challenge provides undergraduate and graduate students working with faculty advisors the opportunity to design, develop, and demonstrate their technology in a project-based program over the course of a year-and-a-half. In FY 2021, NASA selected seven university teams to receive grants (total combined value of nearly $1 million) to develop innovative lunar dust mitigation solutions. Also, in August 2021, NASA launched the 2022 competition, which invites students to develop innovative and cost-effective robots that go beyond wheeled rovers capable of exploring other worlds.

TECHNOLOGY DEMONSTRATION MISSIONS

- The Laser Communications Relay Demonstration (LCRD) project successfully launched on the U.S. Space Force Test Program 3 mission (STP-3) on December 7, 2021 to showcase the unique capabilities of optical communications including bandwidth increases of 10 to 100 times more than radio frequency systems. LCRD will be able to downlink data to Earth over optical signals at a rate of 1.2 gigabits per second and will pave the way for future optical communications missions.
- Designers completed and delivered two key components of the Low-Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID) – the flexible thermal protection system and inflatable structure – were completed and delivered to NASA's Langley Research Center (LaRC) in Hampton, Virginia for testing ahead of its scheduled demonstration in late 2022. LOFTID will demonstrate inflatable atmospheric re-entry technology that enables landing heavy payloads on planetary surfaces and one day helps humans land on Mars.
- Completed Deep Space Optical Communication (DSOC) hardware build and delivered to the SMD Psyche mission in June 2021. Engineers completed integrating the DSOC payload with the Psyche spacecraft and is undergoing ground validation testing leading up to launch in 2022.

Small Spacecraft Technology

- The Small Spacecraft Technology Program launched two successful technology demonstrations – the first Pathfinder Technology Demonstrator (PTD-1) and V-R3x – in January 2021. The projects were facilitated by the program's Payload Accelerator for CubeSat Endeavors (PACE) initiative. PTD-1 became the first to demonstrate a water-based electrolysis propulsion system on any type of spacecraft. The V-R3x trio of CubeSats demonstrated new technologies and techniques for radio networking and navigation.

Flight Opportunities

- NASA launched the TechRise Student Challenge, inviting teams of students from grades 6-12 to design, build, and launch climate, remote-sensing, and space exploration experiments on commercial suborbital rockets and high-altitude balloon flights. A total of 57 winning teams from across the U.S. were announced on January 21, 2022. The Flight Opportunities Program also enabled 84 tests of payloads on commercial suborbital flights in FY 2021 for technologies that will help enable lunar and other long-duration exploration missions, advance space-based manufacturing capabilities and other commercial LEO activity, and further our understanding of the climate models on Earth as well as other planets.

Industry Partnerships

- STMD fostered partnerships with industry to seed commercial markets with enabling technologies that have applicability to and will return to any commercial endeavor for infusion or commercialization. In early FY 2021, NASA awarded a combined $370 million to 14 American companies, including several small businesses, in the area of cryogenic fluid management technology demonstration, which are needed to advance in-situ resource utilization, surface power generation and energy storage, communications, and closed-loop descent and landing capability demonstration. These awards were made under NASA's fifth competitive Tipping Point solicitation to development technologies that will help forge a path to sustainable Artemis operations on the Moon by the end of the decade.
- In early FY 2021, STMD announced its selection of 17 U.S. companies for 20 partnerships to mature industry-developed space technologies for the Moon and beyond through the 2020 Announcement of Collaboration Opportunity (ACO) establishing agreements for a total value of approximately $15 million. The selected proposals are addressing technology challenges related to cryogenic fluid management and propulsion, advanced propulsion, sustainable power, in-situ propellant and consumable production, intelligent/resilient systems and advanced robotics, advanced materials and structures, entry, descent, and landing, and small spacecraft technologies. The NASA and industry teams will design a 3D printing system for NASA's Artemis lunar exploration program, test a simple method for removing dust from planetary solar arrays, mature a first-stage rocket recovery system for a small satellite launch provider, and more.

SMALL BUSINESS INNOVATIVE RESEARCH (SBIR)/SMALL BUSINESS TECHNOLOGY TRANSFER (STTR)

- NASA SBIR/STTR awarded 305 SBIR and 56 STTR Phase I contracts to 287 U.S. small business teams to establish the scientific, technical, and commercial feasibility of their proposed innovation. Additionally, the program made 142 SBIR and 22 STTR Phase II awards to further expand upon prior Phase I work and awarded post-Phase II opportunities to continue technology development towards a NASA mission and/or commercialization.

WORK IN PROGRESS IN FY 2022

EARLY STAGE INNOVATIONS AND PARTNERSHIPS

- STRG continues to partner with researchers across academia and industry to explore transformative technologies and approaches across its Space Technology Research Grants Program elements, featuring regular solicitations and awards across its program elements.
- NIAC continues to solicit and select Phase I, II, and III awards for visionary concepts that address Government and commercial aerospace goals. NIAC also increased the FY 2022 funding values for the 12-month Phase I awards (from $125,000 to $175,000) and the 24-month Phase II awards (from $500,000 to $600,000) to keep pace with the increasing cost of academic and institutional research.
- The Centennial Challenges element of PCC continues to support the following challenges: CubeQuest Challenge, which offers a total of $5 million to teams that meet the challenge objectives of designing, building, and delivering flight-qualified small satellites capable of advanced operations near and beyond the Moon; and the Phase 2 continuation of three lunar-focused Centennial Challenges: Watts

on the Moon, Break the Ice Lunar, and Deep Space Food. NASA is also developing new prize concepts to address climate challenges and/or clean energy economy.

- The Center Innovation Fund (CIF) and Early Career Initiative (ECI) programs continue to engage NASA researchers in the development of advanced technologies to provide future NASA mission capabilities with the internal solicitation call in the March-April time frame with project selection in the fall of 2022.
- Technology Transfer is increasing licensing and commercialization successes as well as increasing novel partnerships by streamlining New Technology Reporting, Intellectual Property Management, Licensing, Software Release. Technology Transfer also supports Technology Transfer Expansion (T2X) activities, which include entrepreneurship initiatives, innovative ecosystem engagement, and partnerships for bringing new products and services to market.

TECHNOLOGY MATURATION

- The Lunar Surface Innovation Consortium (LSIC) currently has over 1,500 participants from more than 600 organizations representing industry, academia, other government agencies, and non-profits from all 50 states and 38 countries. In FY 2022, the Johns Hopkins University Applied Physics Laboratory (APL) will provide Technology Maturation Assessments for the six LSII capability areas as the LSII System Integrator. These assessments will incorporate key insights and feedback from the LSIC industry and university members. This ensures NASA's collaborative opportunities and solicitations result in accelerating the development of cutting-edge technologies, while providing the greatest value-proposition for commercial and academic partners across the United States.
- In October 2021, NASA selected Intuitive Machines of Houston to deliver Polar Resources Ice Mining Experiment-1 (PRIME-1) to the Moon under the Agency’s Commercial Lunar Payload Services initiative. PRIME-1 consists of a lunar drill and mass spectrometer and will demonstrate ice-mining that will help NASA search for ice at the Moon’s South Pole and, for the first time, harvest water from below the surface. NASA will complete final integrated payload and validation and verification testing of the PRIME hardware to Intuitive Machine's Lunar Lander to be sent to the lunar surface for demonstration on an early CLPS mission.
- The Thruster Advancement for Low-temperature Operation in Space (TALOS) project will complete the thruster design and performance testing and Frontier Aerospace TP will deliver qualified flight thrusters for Astrobotic's Peregrine Lander Commercial Lunar Payload Service (CLPS) mission to Lacus Mortis.
- SPLICE will incorporate design changes based on Blue Origin’s New Shepard flight tests and complete development and assembly of the Descent Landing Computer (DLC) and Hazard Detection LiDAR (HDL) engineering test units for a suborbital flight on Masten’s new Xogdor vehicle.

TECHNOLOGY DEMONSTRATION MISSIONS

- OSAM-1 completed an integrated flight demonstration mission Critical Design Review in February 2022.
- DSOC continues to make strides towards a launch in 2022. DSOC will give NASA insight into laser communications capabilities farther than ever before, proving these systems are viable for deep space exploration.

- LOFTID is completing fabrication of flight hardware and Assembly, Integration, and Test (AI&T) activities across all subsystems, leading to flight hardware readiness for Complete System Test (CST) in FY 2022. NASA and United Launch Alliance finalized plans to fly LOFTID as a rideshare with the Joint Polar Satellite System-2 (JPSS-2) spacecraft on the Atlas V. Project delivery to the launch site is currently planned for June 2022 and the current target launch date is September 2022.
- Fission Surface Power: NASA released a solicitation for industry preliminary design efforts of a low-enriched uranium fuel power system. Industry proposals were submitted to NASA in March 2022 for evaluation and selection (targeting contract awards by the end of FY 2022).

Small Spacecraft Technology

The Small Spacecraft Technology Program has 15 small spacecraft missions currently underway in FY 2022 that are projected to launch in the 2022-2023 timeframe, including the following:

- NASA awarded a contract to Rocket Lab USA to launch the Advanced Composite Solar Sail System (ACS3) from New Zealand in 2022. The ACS3 technology demonstration uses composite materials in lightweight booms that deploy from a CubeSat to support a solar sail that uses the pressure of sunlight for propulsion.
- The CAPSTONE (short for Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment) mission is planned to launch in 2022 from Rocket Lab USA's launch site in New Zealand. CAPSTONE is expected to be the first CubeSat to fly in cislunar space – the orbital space near and around the Moon. The mission will demonstrate an innovative spacecraft-to-spacecraft navigation solution at the Moon from a near rectilinear halo orbit slated for Artemis' Gateway.
- The Starling distributed spacecraft demonstration mission will launch no earlier than June 2022 on a Venture Class Launch Services 2 launch with Firefly Aerospace. Starling will demonstrate autonomous swarm technologies using a multi-CubeSat constellation.
- The PTD-3 mission will launch aboard a commercial SpaceX flight in mid-2022. The mission will demonstrate the MIT Lincoln Laboratory TeraByte InfraRed Delivery (TBIRD) optical communication system.

SMALL BUSINESS INNOVATIVE RESEARCH (SBIR)/SMALL BUSINESS TECHNOLOGY TRANSFER (STTR)

- STMD worked with the other NASA mission directorates, centers, and industry to identify subtopics for the FY 2022 Solicitation, which was released in January 2022. While retaining an emphasis on subtopics with a strong relevance to Artemis and the Moon to Mars Campaign, the program also seeks to emphasize subtopics that support climate change and clean energy solutions.
- The SBIR Program will identify and accelerate high-priority technologies drawn from the SBIR portfolio through post-Phase II awards, specifically the use of Phase II sequential awards to accelerate the use of SBIR technologies with a priority to support Artemis and climate change/clean energy objectives. The FY 2022 Civilian Commercialization Readiness Pilot Program opened on November 12, 2021 and proposals were submitted January 18, 2022. The Phase II sequential call for white papers will be released early in Q2 and final selections will be made in Q3. The program continues to hold Phase II-E selection meetings roughly every other month with numerous opportunities for SBIR Phase II awardees to submit Phase II-E proposals every year.

- The program is continuing several activities to encourage participation of underrepresented groups including a cooperative agreement with the MSI STEM Research & Development Consortium (MSRDC) and M-STTR Planning grants with NASA's Minority University Research and Education Project (MUREP).

KEY ACHIEVEMENTS PLANNED FOR FY 2023

EARLY STAGE INNOVATION AND PARTNERSHIPS (ESIP)

The Early Stage Innovation and Partnerships (ESIP) portfolio will continue to focus on engaging with academia and industry to develop cutting edge technologies. NIAC will continue engaging innovators with its Phase I, II, and III solicitations with additional emphasis on reaching underserved communities and institutions. STRG will continue to engage with researchers in academia through its five program elements (NASA Space Technology Graduate Research Opportunities, Early Career Faculty, Early Stage Innovations, Lunar Surface Technology Research, and Space Technology Research Institutes) to accelerate development of groundbreaking high-risk/high-payoff, low-Technology Readiness Level (TRL) space technologies. PCC will continue to seek new ideas to solve NASA's strategic challenges through crowdsourcing challenges, such as the Deep Space Food (food production technologies that provide future lunar crews with safe, nutritious food while in lunar orbit or on the lunar surface), Watts on the Moon (solutions for energy distribution, management, and/or storage on the lunar surface), and Break the Ice (excavating and moving icy regolith and water on the lunar surface). PCC is planning seven to eight rapid/tactical challenges and formulating new climate change challenges. ESIP will also continue to stimulate and encourage creativity and innovation within the NASA centers and early career leaders by funding over 130 CIF and ECI projects that address NASA technology needs and advance national aerospace capabilities.

TECHNOLOGY MATURATION

- GCD has several near-term lunar technology demonstrations aboard Commercial Lunar Payload Services (CLPS) lunar landers. Through partnerships with NASA Science Mission Directorate (SMD), utilizing CLPS missions, STMD is planning to deliver five payloads and experiments to the Lunar surface:
    - Polar Resources Ice-Mining Experiment (PRIME-1): Drill into regolith to determine if water is present on the lunar surface;
    - Deployable Lunar Hopper: Demonstrate the ability to gain access to extreme environments, such as the bottom of craters, not reachable by rovers or other technologies;
    - Nokia 4G/LTE Proximity Communications: First time demonstration a 4G/LTE communications system on the lunar surface;
    - Electrodynamic Dust Shield (EDS): Demonstration to remove dust from multiple surfaces, including glass shields and thermal radiators; and
    - Stereo Camera for Lunar Plume Surface Studies (SCALPSS): Cameras that will provide important data 5about the crater formed by the rocket plume of the lander as it makes its final descent and landing on the Moon's surface.

- Crosscutting technologies to support NASA mission directorates, other government agencies, and industry needs (e.g., Advanced Spaceflight Computing, Advanced manufacturing, and Autonomous Systems and Robotics) will continue into FY 2023 and beyond – focusing on projects such as chip fabrication and qualification of High Performance Spaceflight Computing (HPSC), which will provide the potential of 100 times the computational capacity of current flight processors for the same amount of power.
- In collaboration with industry, academia, and other government agencies, GCD will continue developing essential LSII capabilities required for humans and systems to successfully live and operate on the lunar and other planetary body surfaces. Examples are the Cold Operable Lunar Deployable Arm (COLDArm) project, Moon-to-Mars Planetary Autonomous Construction Technology (MMPACT), and In-Situ Resource Utilization (ISRU) Pilot Excavator, which will continue maturing key technologies leading up to potential CLPS flights in the mid-2020s. Combined, these technology development efforts enable a sustainable habitation on the Lunar surface.
- Continue LSIC and sustain increased partnerships and collaborations with industry, academia, and other government agencies.
- NASA will formulate and initiate implementation of the OSAM Consortium.

TECHNOLOGY DEMONSTRATION

- Starting in FY 2023, NASA and its industry partners (selected as part of the Cryogenic Fluid Management 2020 Tipping Point solicitation) will be preparing for their demonstrations of key technologies for long-term cryogenic fluid management. Cryogenic Fluid Management is essential for establishing a sustainable presence on the Moon and enabling crewed missions to Mars.
- The Solar Electric Propulsion (SEP) project expects to receive the first qualification thruster from Aerojet Rocketdyne at the beginning of the first quarter of FY 2023. The Plasma Diagnostics Package (PDP), a system which will collect flight data related to the plasma environment produced by high-power solar electric propulsion during operation, is expected to be delivered to the Artemis Gateway Power and Propulsion Element (PPE) by Spring 2023.
- OSAM-1 critical hardware work will continue with the robot subsystem, and the SPIDER and Servicing Payloads will be integrated onto the Maxar-provided space vehicle in preparation for environmental testing in FY 2024.
- OSAM-2 will be preparing for its launch aboard a Falcon 9 rocket no earlier than 2023 and, once on orbit, will demonstrate on-orbit additive manufacturing of two structural beams utilizing robotic manipulation and autonomous operations.

Small Spacecraft Technology

The budget request for FY 2023 includes pursuing a rapid technology demonstration mission-of-opportunity-based approach that will improve the ability to work with the entrepreneurial space industry and increase the agility of the Small Spacecraft Technology portfolio. Initial technology demonstration missions of opportunity will use industry partnerships, challenges, SBIR, and other methods to target needs identified by SMD, commercial industry, and other U.S. Government operators of small spacecraft with the goal of bringing projects from start to launch in 24 months.

SPACE TECHNOLOGY

SMALL BUSINESS INNOVATIVE RESEARCH (SBIR)/SMALL BUSINESS TECHNOLOGY TRANSFER (STTR)

The SBIR and STTR program office will place additional emphasis on engaging a broad, diverse base of innovators through the program, especially in engagements with MSIs and HBCUs, in addition to an increased emphasis on entrepreneurial engagement to encourage commercialization and economic impact. Award amounts for Phase I and II awards will be increased for the first time in 10 years (considering inflation) to enable firms to meet NASA's demanding technology needs. The program office will continue to work with all the NASA mission directorates, centers, and industry to identify subtopics including technologies to support human exploration to the Moon and eventually Mars, as well as climate and clean energy challenges.

Programs

EARLY STAGE INNOVATION AND PARTNERSHIPS

Early Stage Innovation and Partnerships spur collaboration with innovators across the Nation to capitalize on the ideas, talent, and experience of a diverse set of contributors to achieve NASA's Agency objectives. STMD funds early stage research and development (TRL 1-3) sourced from academia, industry, entrepreneurs, and the NASA workforce to generate pioneering approaches to the Agency’s difficult and far-reaching exploration challenges. It also puts emphasis on increasing participation by women and socially or economically disadvantaged businesses, HBCUs, and MSIs. NASA sustains these early stage investments at seven to eight percent of the overall Space Technology budget, which includes STRG, NIAC, CIF, and ECI. In addition, NASA funds STMD partnership activities including technology transfer and technology commercialization, and the Agency's Prizes and Challenges activities (e.g., Centennial Challenges and the NASA Tournament Lab). NASA’s Technology Transfer Program ensures NASA’s inventions can be utilized to provide U.S. commercial benefit by tracking, analyzing, and reporting investments and progress, as well as managing patent licenses and software releases.

TECHNOLOGY MATURATION

STMD is advancing revolutionary space technologies from proof-of-concept to demonstration and maturing transformational and foundational technologies across the critical gap that resides between early stage concepts and flight demonstration (TRL 3-6). The Technology Maturation portfolio, which includes the GCD Program, develops and demonstrates technologies needed to support other NASA mission directorates, the commercial space sector, and other government agencies (as appropriate). The portfolio emphasizes technologies aligned with the STMD Technology Thrusts. A portion of the Technology Maturation portfolio is dedicated to the LSII, targeting critical technologies needed for surface activities. In addition, Technology Maturation includes strategic technology investments that are critical for to industry and other Government agency stakeholders.

TECHNOLOGY DEMONSTRATION

The Technology Demonstration portfolio supports ground-based testing to determine feasibility and technology flight demonstrations in relevant environments to effectively transition technologies for

NASA missions and for use by other Government agencies and industry. Through the Technology Demonstration Missions (TDM), Small Spacecraft Technologies (SST), and Flight Opportunities (FO) Programs, ground and flight demonstrations (TRL 5-7) are prioritized to complete multiple projects nearing completion, while demonstrating crosscutting applications applicable to multiple stakeholders.

SMALL BUSINESS INNOVATION RESEARCH (SBIR) AND SMALL BUSINESS TECHNOLOGY TRANSFER (STTR)

The SBIR/STTR programs leverage the Nation's innovative small business community to support research and development efforts that enable NASA's mission in human exploration, science, and aeronautics. SBIR/STTR supports early-stage research and mid-TRL development, performed by small businesses through competitively awarded contracts. These programs provide the small business sector with an opportunity to develop technology for NASA and to commercialize that technology to spur economic growth and potentially address national needs in the aerospace industry and other sectors. These programs produce innovations for both Government and commercial applications. Annual solicitations maintain commitment to an integrated Agency-wide SBIR/STTR program that supports both commercial interests and NASA mission needs, while addressing innovation initiative that aligned with Administration priorities (e.g., climate science); and increase participation by women and socially or economically disadvantaged businesses, HBCUs, and MSIs.

EARLY STAGE INNOVATION AND PARTNERSHIPS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Agency Technology and Innovation	8.4	9.4	**9.6**	9.8	10.0	10.0	10.0
Early Stage Innovation	89.2	115.6	**125.3**	127.6	130.1	137.3	155.6
Technology Transfer	19.9	20.0	**21.0**	22.1	22.6	22.6	22.6
Total Budget	**117.5**	**145.0**	**155.9**	**159.5**	**162.7**	**169.9**	**188.2**
Change from FY 2022 Budget Request			**10.9**				
Percent change from FY 2022 Budget Request			**7.5%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The Center for the Utilization of Biological Engineering in Space (CUBES) Space Technology Research Institute (STRI) has demonstrated biosynthetic production of pharmaceuticals (e.g., use of lettuce plants, pictured above, for production of a parathyroid hormone for bone regeneration), novel LED lighting systems which doubled the rate of plant growth with the same power consumption, bioengineering for drought resistance and increased photosynthesis, and techniques for ISRU-based manufacturing with novel high-strength biopolymers.

Early Stage Innovation and Partnerships spur collaboration with innovators across the Nation to capitalize on the ideas, talent, and experience of a diverse set of contributors to achieve commercialization of aerospace technologies, economic impact, and contributions to NASA's missions.

Early Stage Innovation supports concept studies, applied research, and early technology development that germinate revolutionary ideas, expand innovation, and transform future capabilities. Open innovation capabilities support NASA’s R&D objectives and leverages the Agency’s connection with the American and global public to support NASA's objectives. By leveraging the technical capabilities of experts across the Nation from academia, established industry, new businesses, NASA centers, and individual members of the public, the Agency gains new ideas and alternative approaches to solving NASA’s difficult and far reaching space technology challenges. Recent emphasis has been placed on identifying emerging concepts and technologies that support topics such as Lunar surface requirements and climate change and clean energy challenges.

Within Technology Transfer, NASA responds to Administration priorities and legislative requirements to promote technology transfer, including commercialization of technologies that emerge from NASA’s research and development activities to support commercial expansion in space, economic development, and tangible Earth applications.

EARLY STAGE INNOVATION AND PARTNERSHIPS

Agency Technology and Innovation funds the operations of the Office of the Chief Technologist (OCT), which performs Agency outreach, and promotes innovative culture and partnerships internally and externally.

EXPLANATION OF MAJOR CHANGES IN FY 2023

The FY 2023 Budget expands Early Stage Innovation and Partnerships in order to achieve a gradual increase to 10 percent of STMD's budget by FY 2027. This includes portfolio-wide investments in Diversity, Equity, Inclusion, and Accessibility (DEIA), Agency learning agendas, lab-to-market, and Early Stage Innovation and Commerce.

ACHIEVEMENTS IN FY 2021

Agency Technology and Innovation:

- The OCT continued to serve as the NASA champion for innovation. The office completed the NASA Innovation Portal, which utilizes an intelligent search engine to link NASA employees to people, tools, and activities that facilitate innovation. In addition, several Mission Directorates and centers partnered on collaborative innovation experiments that foster an innovative culture throughout the Agency.
- The Strategic Technology Integration Framework effort developed guidelines for synthesizing the state of NASA’s technology investment portfolio. The guidelines were refined using inputs from the mission directorates and implemented to facilitate mission directorate identification of technology gaps. A Venture Capital study was completed that explored innovative ways to further commercialize and spinoff mature NASA technologies and commercial capabilities to benefit the United States economy.
- The Science and Technology Partnership Forum engaged with interagency partners on joint technology assessments, particularly in low-technology readiness areas. OCT published an interagency report on recommendations that NASA and Government partners will use mature and trusted autonomy technologies. OCT hosted a regular cadence of virtual interagency Science and Technology Forum technical interchange meetings, coordinating technology needs across several Government agencies related to future cislunar space architectures and cybersecurity mission assurance.

Early Stage Innovation:

- The NASA Innovative Advanced Concepts (NIAC) Program continued its advancement of future NASA mission capabilities by announcing 16 Phase I awards in March 2021. Among the new selections are: a lunar levitation track system for efficiently moving excavated regolith and other commodities across the lunar surface; a system that bends sunlight to distribute power to shadowed lunar exploration regions; and a method for making fertile soil from asteroid material to sustain future human colonies in space. Six Phase II studies were also announced in 2021, providing more in-depth analysis of several promising Phase I studies. These include plans for a lunar radio telescope, autonomously constructed in a crater on the far side of the Moon; a low-cost mission to rapidly identify small, fast moving asteroids for planetary defense and future resource mining; and new methods to travel throughout the solar system and explore distant, icy worlds. Following on a successful prior Phase II award, NIAC also awarded a 2-year Phase III study in 2021 to develop a

EARLY STAGE INNOVATION AND PARTNERSHIPS

compact neutrino detector. This will fly close to the Sun to provide a refined understanding of the Sun's energy production and later to study neutrinos emanating from the galactic center to detect the elusive dark matter distributed within our galaxy. Previously selected Phase III studies in FY 2021 include: a deep space mission to the solar gravitational lens to perform multipixel imaging and spectroscopy of an exoplanet; robotic technologies that could enable autonomous lunar roving and the exploration of lunar caves and pits; and techniques for the optical mining of asteroids to reclaim precious volatiles and materials for the continued expansion of humanity into the solar system.

- Space Technology Research Grants (STRG) program continued to partner with researchers across academia and industry to explore transformative technologies and approaches:
  - Released the second Lunar Surface Technology Research (LuSTR) solicitation featuring topics in two LSII focus areas: Extreme Environments and Excavation and Construction. As part of the LSII portfolio, LuSTR solicits ideas from university researchers for the creation of new, enabling technologies that will be needed for lunar surface exploration and to accelerate the technology readiness of key lunar surface exploration systems and components. The six inaugural LuSTR awards in the areas of Surface Power and In Situ Resource Utilization commenced in May 2021.
  - Released its 11th annual call for proposals from graduate student researchers through the NASA Space Technology Graduate Research Opportunities (NSTGRO) solicitation. Students were notified of their selection on April 2, 2021, and the awards, covering multiple technology areas, commenced in August of 2021. The 12th annual NSTGRO call for proposals was released on September 2, 2021.
  - Released the Early Career Faculty (ECF) and Early Stage Innovations (ESI) solicitations in February and April of 2021, respectively, with ECF awards starting in late FY 2021 and ESI in early FY 2022.
  - Awarded two new Space Technology Research Institutes (STRI) from the biennial STRI solicitation released in 2020:

The Advanced Computational Center for Entry System Simulation (ACCESS) Institute will advance the analysis and design of NASA entry systems by developing a fully integrated, interdisciplinary simulation capability focusing on thermal protection systems and prediction of the extreme environments experienced during atmospheric entry.

Joint Advanced Propulsion Institute (JANUS) will work to overcome limitations in ground testing of high-power electric propulsion systems and to improve our understanding of the reliability and performance of these devices when operating in the vacuum of space.

- The Early Career Initiative (ECI), which engages NASA early career researchers with partners in academia and industry, released its annual solicitation to the NASA centers in March 2021. Designed to develop the innovative leaders and technologies of the future, ECI initiated five new projects in FY 2021. These include improved aerodynamic capabilities for future Mars helicopters; methods to alleviate dust contamination and to develop protective hardware coatings that are resistant to lunar dust abrasion; additive manufacturing process to develop tailored reentry heat shields; and using machine learning to improve aerodynamic modeling for robotic and future human landers on Mars. In September 2021, four new ECI awards were selected to begin in FY 2022, ranging from improving parachute dynamics to manufacturing batteries using lunar resources. Each of these projects address

EARLY STAGE INNOVATION AND PARTNERSHIPS

NASA technology needs and directly provide NASA's early career employees with hands-on leadership experience.

- The Center Innovation Fund (CIF) provides seed funding to conduct innovative research at each of the NASA centers, and in 2021 the CIF Program selected 126 projects across a broad spectrum of NASA technology areas. Led by NASA researchers, these highly innovative projects involved 43 academic collaborations, 19 industry partners, and 4 partnerships with other Government agencies to develop these new national aerospace capabilities. While somewhat slowed by the pandemic, These projects continued to progress through 2021, though several have received schedule extensions to complete their projects in calendar year 2021 at no additional program cost. Unique among NASA programs, CIF projects actively push the boundaries of science and technology, allowing NASA to maintain a highly innovative workforce to meet the challenges of 21st century space exploration.
- NASA Prizes Challenges and Crowdsourcing Program continues to conduct challenges and activities to advance space technology outcomes. Three Centennial Challenges completed Phase I competitions focused on human lunar exploration needs: Watts on the Moon (power storage and distribution); Break the Ice Lunar (excavation, manufacturing, and construction); and Deep Space Food (astronaut nutrition). The Prizes Challenges and Crowdsourcing Program also completed numerous multi-year challenges, including:
    - Vascular Tissue Challenge: Create viable, thick metabolically functional human vascularized organ tissue that can be used to advance research and medicine in space and on Earth. Two teams were awarded with a total of $400,000 in summer 2021.
    - CO2 Conversion Challenge Phase II: Using carbon dioxide (CO2) to generate substrates that feed microbial bioreactors to generate essential products for long duration missions. Phase II awarded $750,000 to the top three teams that demonstrated operational systems in FY 2021.
    - Space Robotics Challenge Phase II: a virtual competition to advance robotic software and autonomous capabilities for space exploration missions on the surface of extraterrestrial objects, such as distant planets or moons. Winners were announced in fall 2021 and the award value is $780,000.
    - NASA continues to leverage challenge and crowdsourcing platforms to run innovative competitions through the NASA Tournament Lab that supports a diverse set of problem areas across NASA. Several competitions based on identified technology needs were launched or concluded, including: Lunar Deep Freeze Challenge, Lunar Tele-Operated Rover-based Configurable Heliostat (Lunar TORCH) Challenge, TechRise Challenge, and TechLeap Challenge. The latter two supported STMD's Flight Opportunities Program quest to stimulate rapidly developed small technology demonstration payloads.

EARLY STAGE INNOVATION AND PARTNERSHIPS

Technology Transfer:

- Despite the ongoing global pandemic, NASA's Technology Transfer program executed an all-time record of 211 patent licenses with industry, each of which could become new products and services that benefit the United States taxpayer.
- Software release numbers also broke an all-time NASA record with 5,167 software packages delivered to customers. This high volume of software released to the public are, in part, attributed to an improved online format to request and download NASA software.
- To help bolster this positive licensing and software release trend, the Technology Transfer Expansion (T2X) initiative has taken advantage of the virtual shift that comes with working from home by offering more technology learning opportunities to potential licensees than ever before through a series of webinars. T2X is also ramping up efforts to find and cultivate relationships with regions ready to commercialize NASA technologies across the United States.

WORK IN PROGRESS IN FY 2022

Agency Technology and Innovation:

- NASA will conduct analysis to inform on the Agency's strategic priorities and Agency-wide technology policy in key priority areas related to the space industrial base, resiliency in cislunar architectures, and research and development conducted in Low Earth Orbit during the 2030s. NASA will continue ongoing horizon-scanning studies to assess emerging technology development practices within industry that may provide value to NASA.
- NASA will build on the success of the Science and Technology Partnership Forum, identifying additional areas of mutual interest and technology gaps that may be filled through cooperative interagency efforts. The Chief Technologist will chair the NASA Technology Taxonomy Control Board to guide NASA technology policy.

Early Stage Innovation:

- NIAC will continue to solicit and select Phase I, II, and III awards for visionary concepts that address Government and commercial aerospace goals. Phase I proposal panel reviews were conducted in early FY 2022 to recommend a new slate of projects for award, selections were made in February 2022, and awards to begin by late March 2022. Similarly, Phase II proposals were reviewed in January and selections were made in February 2022 and are expected to be awarded in March 2022. A new Phase III solicitation was released in February 2022, with final proposal selection to occur in May and awards to begin in October 2022. For the first time in over a decade, NIAC will increase the FY 2022 funding values for the 12-month Phase I awards from $125,000 to $175,000; and the 24-month Phase II awards from $500,000 to $600,000; to keep pace with the increasing cost of academic and institutional research. Each 24-month Phase III project award will remain capped at $2 million, phased over the 2-year performance period.
- NASA is continuing to partner with researchers across academia and industry to explore transformative technologies and approaches across its Space Technology Research Grants Program elements, featuring regular solicitations and awards across NSTGRO, ECF, ESI, LuSTR, and STRI. Projects examine the theoretical feasibility of ideas and approaches that are critical to making science,

including climate change and clean energy, space travel, and exploration more effective, affordable, and sustainable.

- The annual CIF and ECI programs will continue to engage NASA researchers in the development of advanced technologies to provide future NASA mission capabilities. The annual CIF process will be initiated at the centers in the March-April 2022 time frame, based on each center's internal solicitation and selection process. Recommended CIF proposals will be submitted to NASA STMD for award consideration in August 2022, with selected projects receiving funds on October 1, 2022. The ECI solicitation will be released to the centers by NASA Headquarters (NASA HQ) in March 2022, with selections planned for September 2022 and awards to begin on October 1, 2022.
- NASA's Prizes Challenges and Crowdsourcing Program continues to support the following Centennial Challenges: CubeQuest Challenge, which offers a total of $5 million to teams that meet the challenge objectives of designing, building, and delivering flight-qualified small satellites capable of advanced operations near and beyond the Moon; and the Phase 2 continuation of three lunar-focused Centennial Challenges: Watts on the Moon, Break the Ice Lunar, and Deep Space Food. NASA is also developing new prize concepts to address climate challenges and/or clean energy economy. Several additional smaller challenges and crowdsourcing activities to support NASA technology needs will also be conducted.
- NASA is expanding Early Stage capabilities with portfolio-wide investments in diversity, Agency learning agendas, and lab to market/transition efforts. Efforts seek to encourage the transition of STMD funded academic research to market through iCorps entrepreneurial training; enabling increased participation by underrepresented and underserved groups; and building evidence to determine what works to advance early stage innovations and partnerships.

Technology Transfer:

- NASA Technology Transfer will continue to streamline and increase new technology reporting; IP management; licensing; software release while also supporting Technology Transfer Expansion (T2X) activities, which include entrepreneurship initiatives; innovative ecosystem engagement; and partnerships for bringing new products and services to market. The goal of these activities is to increase licensing and commercialization.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

Agency Technology and Innovation:

OCT will build on the successes of the FY 2022 analyses studies to inform innovative initiatives that explore the intersection of technology, policy, and strategy including advocacy for NASA research and technology programs through communication and integration with technology efforts being conducted by other Federal agencies. OCT will continue to focus and enable Agency goals, policy, and strategy by maintaining awareness of critical emerging issues, both internal and external to the Agency, engaging leadership as needed, identifying the trade space for key Agency decisions, and conducting independent studies and analyses to support decision making.

EARLY STAGE INNOVATION AND PARTNERSHIPS

Early Stage Innovation:

- NASA will continue NIAC Phase I, II, and III awards with additional emphasis on reaching underserved communities and institutions. NIAC funds over 300 Space technology Research Grants (STRG) awards annually across the Technology Taxonomy selected through 5 funding opportunities: NSTRGO, ECF, ESI, LuSTR, and STRI. NIAC will continue ongoing Prizes, Challenges, and Crowdsourcing (PCC), including Deep Space Food, Break the Ice, and 7-8 Rapid/Tactical challenges; as well as formulating new climate change challenges. NIAC stimulates and encourages creativity and innovation within the NASA centers and early career leaders by funding over 130 Center Innovation Fund and Early Career Initiative projects that address NASA technology needs and advance national aerospace capabilities. NIAC advances ESIP-portfolio joint priorities and enhances support to underserved communities, evidence-driven programs, and academic research to market, such as iCorps grants.
- NASA is targeting to invest $10 million from across the Early Stage Innovation portfolio, STRG, PC&C, CIF, ECI, and NIAC to support and expand portfolio-wide investments in DEIA, Agency learning agendas, Lab to Market, and Early Stage Innovation and Commerce.
- The FY 2023 budget proposes $13.4 million, including $3.8 million in new prize authority plus additional awards to support prizes and challenges in topics ranging from supporting lunar exploration to addressing climate change. This level of new prize funding annually supports a healthy and ambitious portfolio of prize types each year through FY 2027.

Technology Transfer:

- NASA Technology Transfer will continue to streamline and increase new technology reporting, IP management, licensing, software release while also expanding Technology Transfer Expansion (T2X) activities, which include entrepreneurship initiatives seeking to engage more regional ecosystems in the United States to expand venture creation and commercialization, innovative ecosystem engagement, efforts to expand DEIA, and partnerships for bringing new products and services to market. The goal of these activities is to increase licensing and commercialization successes.

Program Elements

AGENCY TECHNOLOGY AND INNOVATION

Agency Technology and Innovation funds the operations of the Chief Technologist and Agency activities that promote innovative culture and partnerships internal and external to NASA.

The NASA Chief Technologist serves as the Agency's principal advisor and advocate on matters concerning Agency-wide technology policy to internal and external stakeholders. The NASA Chief Technologist also communicates and helps to strategically integrate technology efforts within the Agency and conducts regular reviews and assessment of technology investments across NASA, including the mission-focused investments made by the Agency's Mission Directorates, and performing strategic technology integration.

The NASA Chief Technologist hosts several technical interchange meetings in support of NASA's participation in the interagency Science and Technology Partnership Forum activity, an ongoing activity

EARLY STAGE INNOVATION AND PARTNERSHIPS

that brings leaders in Government aerospace, defense, and national security communities together to better coordinate Federal investments and activities based on mutual critical needs and future plans. These exchanges are working to identify partnership opportunities that reduce duplication of effort and investment across Government while advancing the TRLs and infusion paths that will benefit Agency missions. In addition, the NASA Chief Technologist continues to work closely with internal and external stakeholders to develop strategies to expand NASA's innovation ecosystem and the development of an Agency innovation framework.

EARLY STAGE INNOVATION

NASA's Early Stage Innovation activities employ various approaches to engage subject matter experts at universities, companies, independent labs, NASA centers, and other Government agencies. Through a steady cadence of competitive solicitations, NASA continuously develops new and innovative high-risk/high-payoff technologies. Early Stage studies cultivate new ideas and alternative approaches and leverage the technical capabilities of the experts across the Nation that can fuel economic growth. Technologies are often developed with support and coordination among NASA and various external partners and primarily focus on innovative ways to further humankind's exploration from conception to testing to spaceflight. NASA awards early stage efforts through Space Technology Research Grants, NASA Innovative Advanced Concepts, the Center Innovation Fund, and the Early Career Initiative and innovation efforts through the Prizes, Challenges and Crowdsourcing Program. Open innovation capabilities support NASA's R&D objectives and leverages the Agency's connection with the American and global public to support NASA's objectives. By leveraging the technical capabilities of experts across the Nation from academia, established industry, new businesses, NASA centers, and individual members of the public, the Agency gains new ideas and alternative approaches to solving NASA's difficult and far-reaching exploration challenges. Early Stage Innovation and Commerce activities advance priorities and collaboration across Early Stage Innovation, Technology Transfer, and SBIR/STTR by enhancing support for underserved communities, evidence-driven programs, and academic research to market.

It is not always clear which efforts will result in breakthroughs, effective improvements, or exciting new approaches. The technology innovation process is nonlinear and takes time. Therefore, a balance of early stage, mid-Technology Readiness Level (TRL), and technology demonstration investment is critical for an effective technology development portfolio.

Space Technology Research Grants

STRG conducts a series of annual and biennial competitive solicitations targeting high-priority technologies that engage the entire spectrum of academic researchers, from graduate students to early career and senior faculty members. STRG emphasizes technology that can make space activities more effective, affordable, and sustainable. In the process, close collaborations between United States universities and NASA centers are established and nurtured. The NASA Space Technology Graduate Research Opportunities solicitation seeks to sponsor graduate researchers who show significant potential to contribute to NASA's goal of creating innovative new space technologies for our Nation's exploration, science, and economic future. The topics featured in the Early Career Faculty, Early Stage Innovations, Lunar Surface Technology Research, and Space Technology Research Institutes solicitations are of high priority to NASA and the aerospace community and focus on areas where it is anticipated that academia is ideally suited to provide significant contributions.

EARLY STAGE INNOVATION AND PARTNERSHIPS

STRG funds innovative space technology research and currently features more than 300 active grants to United States universities. In FY 2021, NASA made 58 NASA Space Technology Graduate Research Opportunities awards, six Early Career Faculty awards, 14 Early Stage Innovations awards, six Lunar Space Technology Research awards, and two Space Technology Research Institute awards. The program has supported research projects at 116 universities across 45 States since its inception in 2011.

STRG awards result in numerous technology transition successes and contributions to NASA's mission:

- Modeling Oxygen Production on Mars and Extension to a Human-Scale Mission: Eric Hinterman, a NASA Space Technology Graduate Researcher from the Massachusetts Institute of Technology, created a high-fidelity model of the oxygen producing MOXIE experiment onboard the Science Mission Directorate Mars 2020 mission's Perseverance rover. His model is used extensively by the MOXIE team to test and validate commands sent to the experiment. Eric now serves as the MOXIE payload uplink lead during Perseverance Mars surface operations.
- Reduced Order Modeling for Non-equilibrium Radiation Hydrodynamics of Base Flow and Wakes: Enabling Manned Missions to Mars: Marco Panesi, an Early Career Faculty Principal Investigator from University of Illinois at Urbana-Champaign, developed new high-fidelity models of radiation on a planetary entry vehicles backshell. The new algorithm drastically accelerates the calculation of the radiation heat-loads in the wake of the spacecraft, without sacrificing fidelity. His model was used during aerothermal entry simulations of the Mars 2020 mission.
- Poly(ionic liquid)-ionic liquid membranes reinforced by graphene sheets for carbon dioxide capture and conversion in microgravity: Burcu Gurkan, an Early Career Faculty Principal Investigator from Case Western Reserve University, developed new advanced materials to reduce cabin CO2 concentration for life support systems. Her ionic liquid-based materials exceed the state of the art in CO2 absorption and have potential to extract oxygen with additional development. The technology may also have applications for CO2 capture on Earth.
- Assistive Free-Flyers with Gecko-Inspired Adhesive Appendages for Automated Logistics in Space: Mark Cutkosky, an Early Stage Innovations Principal Investigator from Stanford University, developed a new gripper for the Astrobee robots used onboard the ISS which can grip and hold objects using Van der Waals forces, similar to a gecko's feet. The gripper allows the robots to grasp or perch onto nearly any flat surface onboard the space station, greatly increasing their capabilities and was successfully tested onboard the ISS.

NASA Innovative Advanced Concepts

NIAC executes annual solicitations seeking exciting and unexplored, but technically credible, new concepts that could one day "change the possible" in space and aeronautics. These efforts improve the Nation's leadership in key research areas, enable long-term capabilities and spawn disruptive innovations that make space exploration more effective, affordable, and sustainable.

Phase I and continuation Phase II solicitations are open to NASA centers, other Government agencies, universities, industry, and individual entrepreneurs. NASA implemented Phase III studies to complement its portfolio of Phase I and Phase II concepts for the first time in FY 2019. Phase III studies are designed to continue maturation of Phase II transformative ideas allowing NASA to strategically transition the most promising NIAC concepts to other NASA programs, other Government agencies, or commercial partners.

EARLY STAGE INNOVATION AND PARTNERSHIPS

Since its reincarnation as a NASA-led program in 2012, NIAC has been a regular source of transformative aerospace concepts and innovative approaches across the aerospace community. The path toward the successful 2021 flights of the Ingenuity helicopter on Mars originated with inspiration provided by an early NIAC study on the use of microelectromechanical systems (MEMS) on a rotorcraft for exploring Mars or Saturn's moon, Titan, which demonstrated that very small rotorcraft could be used successfully in planetary science missions. A prior NIAC study on an advanced fusion propulsion source was successfully transformed into a terrestrial fusion research company, which this year received over $500 million in private investments for further research and development. Another NIAC study on a direct drive nuclear engine approach led to a recent United States patent and additional funding by the Department of Energy to continue development of this promising approach for terrestrial applications. NIAC funded studies in 2015 and 2016 led to the technical approach used in the privately funded Breakthrough Starshot project to develop ultra-fast light-driven miniature spacecraft, laying the foundation for a science mission to the next star within the next few decades. Through multiple innovative studies, NIAC has continued to expand the boundaries of what's possible and to inspire innovators across the broad national landscape.

Center Innovation Fund

CIF provides annual seed funding to each NASA center and NASA's Jet Propulsion Laboratory to stimulate aerospace creativity and workforce innovation to transform future missions and advance national aerospace capabilities. CIF activities are proposed by the centers and competitively selected by NASA HQ to explore alternative approaches or develop enhanced capabilities that will advance NASA mission capabilities. Partnerships with academia, private industry, individual innovators, as well as among NASA centers and Government agencies, are highly encouraged.

Each year an integrated review of candidate CIF projects is conducted by NASA HQ to ensure a strategic and coordinated investment portfolio. These investments have led to multiple successful NASA and commercial applications. Since its inception in 2011, CIF has generated over 350 technical publications, more than 300 NASA Technical Reports, over 90 patents and patent applications resulting in over a dozen commercial licenses, and two spin-off companies that are further developing CIF concepts into commercial products. As seed funding for advanced capabilities, CIF projects often mature through multiple funding paths into a new capability for NASA and the nation.

Early Career Initiative

As an element of the Center Innovation Fund, the ECI provides the opportunity for NASA early career civil servants to propose and work on two-year technology projects with industry and academic partners, engage in hands-on technology development opportunities, and learn different approaches to project management. To maximize the effectiveness of the early career projects, each team is mentored by more senior center personnel and NASA STMD subject matter experts. Several ECI projects have targeted technology demonstrations or flight opportunities that support lunar surface operations, providing NASA civil servant innovators the opportunity to have their technologies demonstrated on the lunar surface. Designed to invigorate NASA's technology base and champion innovative management processes, ECI successfully partners NASA early career leaders with external world-class innovators to deliver transformative national space capabilities. Examples of recently completed ECI projects include a new method for precision landing on atmospheric bodies, a robust astronaut helmet display for improved situational awareness, robotic manipulators for autonomous habitation construction on the Moon and Mars, and robust optical beam steering technologies for lightweight lidar applications. Ongoing projects

EARLY STAGE INNOVATION AND PARTNERSHIPS

range from the development of complete nanosensors on a chip to the autonomous offloading of cargo on future government and commercial lunar landers. While developing critical future NASA capabilities, ECI projects also develop the leadership and team capabilities of our NASA early career workforce, ensuring NASA remains a cutting-edge Agency in this burgeoning epoch of international and commercial space programs.

Prizes, Challenges, and Crowdsourcing

NASA recognizes the value of incentivizing new technology advancement and problem solving through open innovation approaches, including the use of prize competitions and challenges open to the public. Government and non-Government organizations have demonstrated the value of prize competitions for their ability to tap into new sources of talent they have not typically reached. Prize competitions also reduce risk to the buyer because payments only occur after receipt of satisfactory solutions.

STMD's Prizes, Challenges, and Crowdsourcing Program utilizes the NASA Tournament Lab to enlist crowdsourcing to tackle challenges faced in its space and aeronautics research and development programs. The NASA Tournament Lab, which is managed by the Center of Excellence for Collaborative Innovation, offers a wide variety of open innovation platforms that engage the crowdsourcing community in challenges to create the most innovative, efficient, and optimized solutions. When challenge owners were surveyed, NASA users of these tools have found them useful for meeting their needs in 94 percent of cases. Other Federal agencies use the NASA platform on a reimbursable basis. The NASA Tournament Lab also supports NASA@Work, an internal crowdsourcing and challenge platform designed to improve the ability of NASA employees to connect with others within the Agency to solve technical and non-technical problems. This platform played a vital role for the Agency in canvassing the workforce in the fall of 2021 for ideas to enhance the Agency's DEIA-driven outreach initiatives.

Centennial Challenges offer incentive prizes to generate revolutionary solutions to support advanced NASA technology needs and, where appropriate, partners with other organizations to maximize return on investment. NASA has launched three challenges that will address lunar excavation, manufacturing, construction, lunar power needs, and nutrition needs of astronauts.

- Watts on the Moon Challenge: The purpose of this challenge is to identify flexible, robust energy distribution, management, and storage solutions to power upcoming Moon missions. Phase 1 awarded the full $500,000 prize purse to seven teams for their promising design concepts.
- Break the Ice Lunar Challenge: NASA launched Phase 1 of this competition in November 2020. 13 teams shared in the Phase 1 $500,000 prize purse for their concept designs. The challenge's goal of finding solutions to autonomous icy regolith excavation technologies for near-term lunar missions that address key operational elements and environmental constraints.
- Deep Space Food Challenge: This competition launched Phase 1 in January 2021 and awarded $450,000 to 18 teams for their design concepts in support of the competition's goal of seeking novel technologies, systems, and/or approaches for nutritious food production to support long duration space exploration missions. This competition is running in coordination with the Canadian Space Agency, which is running a parallel competition and will judge and award Canadian citizen competitors with a separate prize purse.

The FY 2022 Budget proposes new prize authority (no-year funding) to support multi-year challenges. This will continue the Phase 2 prizes for Break the Ice Lunar Challenge and the Deep Space Food

EARLY STAGE INNOVATION AND PARTNERSHIPS

Challenge in addition to new prizes, challenges, and crowdsourcing activities related to climate and clean energy economy. In addition, active Centennial Challenges in progress include Cube Quest Challenge and the Watts on the Moon Challenge.

Early Stage Innovation and Commerce (ESIC)

The Early Stage Innovation and Partnerships (ESIP) portfolio was created in FY 2021 to help drive impact, innovation, and transitions in STMD's early stage and commercialization work. This portfolio of programs seeks to increase impact through strategic coordination between the Early Stage Innovation, Technology Transfer and SBIR/STTR programs, as well as collaboration with higher TRL programs in STMD and across NASA. ESIP portfolio activities advance priorities including enhanced support in DEIA, evidence driven programs, industry collaboration and commercialization/economic growth. ESIC addresses several ESIP/STMD gaps complementing other existing programs, including:

- Increasing emphasis on DEIA and participation by underrepresented and underserved communities across STMD programs.
    - Enables STMD to further leverage Minority University Research and Education Project (MUREP) relationship expanding reach and funding to Minority Serving Institutions and Historically Black Colleges and Universities and other underserved individuals and communities.
    - Enables extramural funding opportunities including expanded planning grants and sustained capacity building grants to underrepresented entities tied to technology needs of the NASA and industry.
- Increasing the rate of transition from university labs to market by actively supporting entrepreneurship in university-based research. Supports a joint effort between the Science Mission Directorate and STMD to expand iCorps training to reach a larger community of researchers in partnership with the National Science Foundation to spinoff companies and create jobs.
- Building capability for evidence-driven evaluation and technology transition. This funding advances STMD's portion of the Learning Agenda consistent with the Evidence-based Policy Making Act of 2018 by supporting an annual Agency evaluation of ESIP programs to advance programmatic impact. To advance technology transition this funding also supports system level or strategic studies to bridge between low TRL and mid TRL programs.
- Initiates new partnerships for early-stage research. ESIC will advance innovative methods to increasing the impact of NASA early stage technology development, including testing the potential of non-profit partnerships to leverage philanthropic capital to advance space technology research.

TECHNOLOGY TRANSFER

Technology Transfer provides Agency-level management and oversight of NASA-developed and NASA-owned intellectual property and manages the transfer of these technologies to external entities. Activities include active collection and assessment of all NASA inventions, strategic management and marketing of intellectual property, negotiation and management of licenses, software releases, development of technology transfer-focused partnerships, and the tracking and reporting of metrics related to these activities (e.g., numbers of new inventions, patents, licenses, cooperative research and development agreements, or software use agreements). NASA Technology Transfer ensures that

EARLY STAGE INNOVATION AND PARTNERSHIPS

innovations developed for exploration and discovery are broadly available to the public, maximizing the benefit to the Nation.

T2X, NASA's Technology Transfer Expansion initiative, accelerates commercialization of NASA patented technologies through outreach, strategic partnerships, and entrepreneurial projects that expand NASA's presence, create an entrepreneurial workforce, and increase national economic impact. Focused on regions across the Nation where is there evidence of highly concentrated resources to support and catalyze high-tech sustainable startup ecosystems, T2X engages in innovative entrepreneurial ecosystem activities and with institutions of higher education to increase licensing and commercialization success.

NASA's Technology Transfer System (NTTS) platform provides Technology Transfer personnel with tools to facilitate the entire technology transfer process, and it enables NASA to track activities in fine-grained, quantifiable detail.

TECHNOLOGY MATURATION

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**227.1**	**491.2**	**471.6**	**481.1**	**491.2**	**497.6**	**493.1**
Change from FY 2022 Budget Request			**-19.6**				
Percent change from FY 2022 Budget Request			**-4.0%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Blue Origin is shown here conducting a suborbital flight with precision landing technology developed under the Technology Maturation SPLICE project, including a descent and landing computer, terrain relative navigation, power-descent guidance, and Doppler lidar.

NASA is advancing revolutionary space technologies from proof-of-concept to demonstration, maturing transformational and foundational technologies that primarily reside between early stage research and flight demonstration. The Technology Maturation investment portfolio provides transformative and crosscutting technologies that contribute to U.S. leadership in space technology and support NASA missions, including human and robotic exploration of the Moon, Mars, and beyond. Technology Maturation is also committed to supporting advancements in clean energy by collaborating with industry in research and development projects for fuel cells and solar technology.

Technology Maturation includes a broad array of crosscutting technology applications that fulfill multiple stakeholder needs, including NASA's mission directorates, commercial industry, and other government agencies. Example technologies include autonomous landing and hazard avoidance, advanced materials, and in-space manufacturing and assembly. These types of technologies could benefit human and robotic exploration and spur economic growth in the space industry. NASA's Industry & Commerce Innovation Opportunity will continue to expand upon the utilization of existing Space Technology Mission Directorate (STMD) acquisition vehicles (e.g., Announcement of Collaborative Opportunity [ACO] and Tipping Point [TP]). This opportunity will provide open topic calls for industry to identify and propose activities that will further enable commercial development of key technologies, which will support creating good paying jobs in a growing U.S. space industry.

TECHNOLOGY MATURATION

Industry partnerships are an important mechanism used by NASA for Technology Maturation projects. Such agreements enable NASA and private sector industry to share in the risk and benefit of common technology development interests and investments. These shared risks and benefits include incentivizing technical performance, enabling the commercial space economy, and sharing financial interests in the development of capabilities that support both NASA and other stakeholder needs. These industry partnerships are primarily developed through NASA's TP and ACO solicitations. In FY 2022, NASA is executing 16 TPs and 26 ACOs. The next cycle of ACO/TP awards is anticipated to be selected in FY 2023.

The Lunar Surface Innovation Initiative (LSII) is also a component under Technology Maturation. Through LSII, STMD collaborates and partners with industry, academia, and other government agencies to develop crosscutting technologies that provide key lunar surface capabilities and feed forward to Mars and beyond. Since its inception in 2019, LSII has engaged over 400 organizations across 48 states and Puerto Rico to advance the technologies needed to explore the lunar surface and stimulate economic development.

Elements of LSII include:

- In-Situ Resource Utilization (ISRU) with an emphasis on collecting, processing, storing, and using material found or manufactured on other astronomical objects;
- Sustainable Surface Power, enabling continuous power throughout lunar day and night;
- Surface Excavation/Construction to enable affordable, autonomous manufacturing and construction;
- Dust Mitigation Technologies to address lunar dust hazards; and
- Extreme Environments and Extreme Access capabilities to operate through the full range of surface and subsurface conditions.

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

TECHNOLOGY MATURATION

PROGRAM ELEMENTS

Technology Maturation Budget Estimated by Focus Area

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Space Transportation	11.0	29.7	26.6	32.5	30.0	30.0	30.0
Entry, Descent and Landing	44.3	52.8	50.3	52.3	44.3	35.5	42.0
Sustainable Exploration	105.7	191.9	159.7	166.4	234.4	237.3	223.5
Discover and Explore	41.0	98.1	113.5	100.5	40.3	47.9	49.2
Industry & Commerce Inn Oppt (ACO/TP)	0.0	85.6	88.0	95.4	107.6	111.8	112.8
Space Tech Management and Integration	25.1	33.1	33.6	34.1	34.6	35.1	35.6
Total Budget	**227.1**	**491.2**	**471.6**	**481.1**	**491.2**	**497.6**	**493.1**

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Sums may not add to Total Budget due to rounding.

PROJECT OVERVIEWS

Technology Maturation has a broad portfolio of more than 120 projects, with more than 70 percent of projects including partnerships and collaborations with industry, academia, and/or other government agencies. The portfolio includes a combination of mid-Technology Readiness Level (TRL) ground-based and flight demonstration developments.

SPACE TRANSPORTATION

NASA is making progress to advance technologies that support rapid and efficient in-space transportation that reduce transit times. Propulsion investments focus on higher thrust and efficiency, including alternatives to traditional chemical propulsion systems for deep space exploration spacecraft systems, and advancement of additive manufacturing (AM) techniques. Specific investments include:

- Thruster for the Advancement of Low-temperature Operation in Space (TALOS) is a new class of thruster that uses propellants that can operate in space for extended periods without freezing. This capability lowers overall spacecraft mass and power needs and reduces mission costs since special heaters are not needed to keep the propellants from freezing. Through a partnership with NASA, Frontier Aerospace is providing the first flight set of axial thrusters for the Astrobotic Peregrine Lunar Lander Mission One. TALOS will begin the design of a “deep space variant” of the current axial and attitude control system thruster designs. These thrusters will be capable of operating with propellants at lower temperatures for longer durations, which will further reduce the mass of future spacecraft and increase payload-carrying capabilities for deep space exploration.
- Rapid Analysis Manufacturing Propulsion Technology (RAMPT) advances state-of-the-art additive manufacturing techniques that will reduce lifecycle development time and costs, along with reducing

system weight and improving performance, to fabricate liquid rocket engine components. Specifically, RAMPT is advancing large-scale, light-weight manufacturing techniques and analysis capabilities required to reduce design and fabrication cycles (by 60 percent) for regenerative-cooled liquid rocket engine components. A partnership with Auburn University provides a 25 percent cost share with the technology manufacturing vendors and will strengthen the U.S. supply chain in these manufacturing areas. This project will culminate in a large-scale Thrust Chamber Assembly hot-fire test.

- Refractory Alloy Additive Manufacturing Build Optimization (RAAMBO) will advance additive manufacturing using refractory alloys. Furthermore, the project will use an integrated computational materials engineering approach verified through testing of prototypes in high temperature environments.
- Composite Technologies for Exploration - Thermoplastic Development for Exploration Applications (CTE-TDEA) is advancing thermoplastic composite capabilities by developing structural joining solution methods for aerospace structures (e.g., lunar landers, on-orbit assembly of large-scale structures, and launch vehicle applications).
- NASA currently funds 42 active collaboration (ACO and TP) projects with a broad range of industry partners. These ACO and TP projects advance rapid and efficient in-space transportation technologies that include additive manufacturing, propellant development from ISRU, new material systems, and engine subcomponents.

ENTRY, DESCENT, AND LANDING

For NASA to land more mass more accurately on planetary bodies, as well as improve capabilities to return spacecraft from low-Earth orbit (LEO) and deep space, the Agency has been working to develop capable Entry, Descent, and Landing (EDL) systems, materials, and computer modeling capabilities. NASA investments have focused on: precision landing and hazard avoidance; design, analysis, and testing of advanced materials for thermal protection; and EDL architectures for future exploration vehicles and planetary entry missions. Key projects within EDL include:

- Safe and Precise Landing – Integrated Capabilities Evolution (SPLICE) enables safer and more accurate lunar landings than ever before. Upcoming Moon missions will use SPLICE's advanced algorithms and sensors to target landing sites not possible during the Apollo missions, such as regions with hazardous boulders and nearby shadowed craters.
- Mars Environmental Dynamics Analyzer (MEDA) is a suite of environmental sensors aboard the NASA Mars 2020 Perseverance rover that characterizes the climate, including wind speed, near the Martian surface. These sensors include dust, optical, radiation, and temperature, as well as a camera for remote observation. The data collected from these sensors will be used to improve landing precision for future Mars missions.
- Plume Surface Interaction (PSI) Mini-Suite will measure thrust and altitude dependent PSI characteristics during a Commercial Lunar Payload Services (CLPS) lunar landing. Lunar dust is an obstacle to achieving a sustainable human presence on the Moon, and lunar landers will be a major source of dust transport across the lunar surface.
- Stereo Camera for Lunar Plume-Surface Studies (SCALPSS) is composed of tiny cameras placed around the base of the commercial lunar lander that monitor crater formation from the precise

moment a lander's hot engine plume begins to interact with the Moon's surface. This data coupled with the PSI project will be used by future lunar lander vehicle designs. SCALPSS is a collaboration with NASA's Science Mission Directorate (SMD).

SUSTAINABLE EXPLORATION

NASA is also working on capabilities for sustainable living and working farther from Earth to support routine crewed operations beyond LEO. Technologies demonstrated will enable humans to live and operate on the Moon and, eventually, Mars. Additionally, these capabilities provide the ability to reach challenging sites and resources on the Moon and Mars to survive and operate through the lunar night. Descriptions of these capabilities are listed below.

Cross-Cutting Sustainable Living

NASA will advance synthetic biology, in-space manufacturing, and intra-vehicle robotics in order to enable and sustain human presence in space. Key projects within this portfolio include the following:

- Spacecraft Oxygen Recovery (SCOR) will advance oxygen recovery technologies to be used in human spacecraft Environmental Control and Life Support Systems (ECLSS) for long-duration missions. Recycling space vehicle and habitat cabin atmospheres will be vital to lowering mission costs and attaining spacecraft self-sufficiency by reducing the mass and volume of life-support consumables, such as oxygen, which need to be carried from Earth.
- Synthetic Biology will demonstrate producing high-value bio-nutrients on demand, minimizing the need for launched resources. This capability allows biomanufacturing systems to scale to viable production systems for mission products, such as food components, pharmaceuticals, polymers, fuels, and a range of valuable chemicals. This technology will enable the availability of nutrient-rich foods to maintain astronaut health for long duration missions.
- Integrated System for Autonomous and Adaptive Caretaking (ISAAC) will enable autonomous caretaking of spacecraft, primarily during uncrewed mission phases. The focus on integrating autonomous intra-vehicular robots (IVRs) with spacecraft infrastructure (e.g., power, life support) and ground control will provide new capabilities for in-space operations and adaptive vehicle caretaking.
- In-Space Manufacturing (ISM) provides a solution towards sustainable, flexible missions (both in-transit and on-surface) through on-demand fabrication, repair, and recycling capabilities for critical systems, habitats, and mission logistics and maintenance. These additive manufacturing capabilities provide tangible cost savings by reducing launch mass, as well as significant risk reduction by decreasing dependence on spares and/or over-designing systems for reliability. This technology will continue to be demonstrated on the ISS.

Lunar Surface Innovation Initiative (LSII)

Through LSII, NASA, in collaboration with industry, academia, and other government agencies, will develop the essential capabilities required for humans and systems to successfully live and operate on the lunar and other planetary body surfaces. These novel technologies will operate through a broad range of lunar environments and will result in the capability to extract and utilize local resources, generate surface power and store energy, access and navigate a variety of terrains, autonomously excavate lunar surface materials for manufacturing and construction, and mitigate lunar dust. Key activities and elements of this initiative are described below.

TECHNOLOGY MATURATION

In-Situ Resource Utilization (ISRU)

ISRU will develop and demonstrate technologies to use the Moon's resources to produce water, fuel, and other supplies. These activities will validate high-fidelity ISRU systems' mass, power, and volume data for incorporation into large-scale flight projects. Following development and maturation of ISRU technologies at the component, subsystem, and scaled system levels, this effort will demonstrate the ability to produce propellants, other mission consumables, products, and infrastructure from regolith and atmospheric resources from a variety of destinations.

- Polar Resources Ice Mining Experiment-1 (PRIME) will be the first ISRU demonstration on the Moon. The project includes a flight-ready instrumentation package that will robotically sample and analyze for ice from below the surface. PRIME is a critical instrument suite that will be integrated on the Intuitive Machines commercial lunar lander to land at the lunar South Pole to assess the volatiles and determine water content. PRIME will help provide the knowledge necessary to find critical resources to produce propellant, water, and oxygen for lunar missions.
- The ISRU Sub-Scale Plant demonstrates critical technologies on CLPS landers (e.g., mining and processing of oxygen and water, excavation, mineral beneficiation, and regolith processing).

Sustainable Surface Power

NASA is making critical advancements in power generation and energy storage technologies for exploration missions. These technology advancements will provide the capability for continuous power throughout day and night operations on the lunar surface. Solar array technology under development can generate energy in extreme environments, including low-light intensity and low temperature. In addition, NASA is developing and demonstrating a primary fuel cell system to support operations with long discharge times, including applications on rovers, powering of habitats, powering in-situ resource utilization systems, and for general energy storage.

- Vertical Solar Array Technology (VSAT) will develop, through the release of multiple contracts with industry, lightweight solar arrays capable of autonomous ten-meter vertical deployment on uneven terrain. This technology will enable near continuous capture of sunlight by the solar arrays at the lunar South Pole region.
- Through TP awards, NASA collaborates with industry partners to develop and test surface power generation and energy storage technologies. Masten Space Systems will develop a universal chemical heat and electrical power source attachment that enables payloads to survive the extreme environments encountered during the lunar night and in craters. pH Matter will develop a reversible, regenerative fuel cell capable of producing power and storing energy on the lunar surface. Precision Combustion will develop a solid-oxide fuel cell stack that generates power directly from methane and oxygen propellants and other in-situ resources.

Dust Mitigation

Lunar dust is one of the principal issues that NASA must address before returning to the surface of the Moon. It has the potential to affect every lunar architecture system. NASA will develop and demonstrate technologies and concepts to mitigate lunar dust hazards; enabling affordable, sustained operations both on the lunar surface and with transfers to and from the Lunar Gateway or other orbital platforms.

- Electrodynamic Dust Shield (EDS) is an active dust mitigation technology demonstration that uses electric fields to move dust from surfaces and to prevent accumulation on surfaces. Potential applications include thermal radiators, spacesuit fabrics, visors, camera lenses, solar panels, and many other technologies. An EDS flight demonstration is scheduled for a Commercial Lunar Payload Services (CLPS) mission in 2023.

- Lunar Occupancy Dust-Surface Separation Technologies (LO-DuSST) is a passive mitigation strategy that involves applying robust ceramic coatings to the surface of metal-based components susceptible to lunar dust abrasion. This extends the lifetime of parts while decreasing overall component weight. NASA is developing Classifications and Standards for Testing with Dust that will identify sources of lunar dust, both natural and induced, particulate size range, surface loading, volumetric loading, and dust velocity. It will define testing types, simulants, facilities, and include detailed test plans (e.g., protocols for abrasion testing). The integrated test plans will span surface operations, landing vehicles, and orbital assets.

Excavation and Construction

NASA will develop and demonstrate technologies that enable affordable, autonomous manufacturing and construction (e.g., of a landing pad, berm, or shielding) using lunar surface materials. Critical to NASA's ISRU Sub-Scale Demo Plant is the ability to excavate regolith under lunar environmental conditions, which include lunar dust, extreme temperatures, and minimal gravity.

- Moon-to-Mars Planetary Autonomous Construction Technology (MMPACT) will utilize lunar in-situ materials for the on-demand construction of large-scale infrastructure elements such as habitats, berms, landing pads, and blast shields. These structures will provide protection of crewmembers, hardware, and electronics while on the surface of an extraterrestrial body to enable sustained surface exploration. Partners include: ICON, Space Exploration Architecture (SEArch+), the Department of Defense (DoD) Innovation Unit, and the United States Air Force.
- ISRU Pilot Excavator will demonstrate a 30-kilogram Regolith Advanced Surface Systems Operations Robot excavator capable of supplying the full feedstock to an ISRU pilot plant, first in a ground demonstration followed by a lunar surface demonstration.

Extreme Environments

NASA advances rovers, manipulators, and other systems that can operate throughout the full range of lunar surface conditions, including lunar noon (up to 150 degrees Celsius), lunar night (down to -180 degrees Celsius), multiple day/night cycles, and permanently shadowed regions (down to -240 degrees Celsius). Key technologies include:

- Bulk Metallic Glass Gears (BMGG) will improve rover mobility performance at low temperatures by creating alloys made of "metallic glass" eliminating the need for gear lubricant and associated heaters. This project will deliver planetary gears and strain wave gears that will enable surface missions where temperatures drop below the freezing point of typical lubricants.
- Cold Operable Lunar Deployable Arm (COLDArm) will significantly improve the utility for lunar landers by providing autonomous manipulation capabilities during the lunar night. It will expand the science capabilities of lunar robotic missions, including deploying instruments, payloads, and sampling.

TECHNOLOGY MATURATION

DISCOVER AND EXPLORE

Extreme Access

STMD demonstrates technologies that enable humans or robotic systems, particularly autonomous systems, to efficiently access, navigate, and explore previously inaccessible lunar or planetary surface or subsurface areas.

- Cooperative Autonomous Distributed Robotic Exploration (CADRE) will incorporate technology developed by Pop Up Flat Folding Exploration Robot and demonstrate collaborative autonomous exploration on the lunar surface by navigating, communicating, computing, perceiving, and decision-making without human interaction.
- Inspired by terrestrial technology, Nokia, through a TP contract, will deploy the first LTE/4G communication system on the lunar surface. The system aims to support lunar surface communications at greater distances and increased speeds, and to provide more reliability than current standards.
- Intuitive Machines will develop a small, deployable hopper lander capable of carrying a 2.2-pound payload more than 1.5 miles. This hopper will access lunar craters and enable high-resolution surveying of the lunar surface over a short distance.
- The high-TRL LIDAR project will develop a vision mapping system that will enable rovers to venture beyond benign planetary and lunar surfaces into dark, high-contrast, confined, or low-texture (i.e., extreme) environments.

On-Orbit Servicing, Assembly, and Manufacturing

Key projects within this portfolio include the following:

- STMD will initiate an On-Orbit Servicing, Assembly and Manufacturing (OSAM) consortium focused on developing technologies needed by the commercial space industry. This consortium will include participants from government departments and agencies, universities, non-profit research institutions, commercial companies, the space start-up community, and under-represented companies (i.e., small and minority-owned businesses) who have a shared commitment to OSAM as an enabling technology and as a means for workforce development.
- Super-lightweight Aerospace Composites (SAC) will scale up the manufacturing and use of high-strength carbon nanotube composite materials leading to significant mass savings in rocket and spacecraft structures.
- Precision Assembled Space Structure (PASS) will develop and validate critical technologies, such as autonomous assembled structures and high-precision joints for effective efficient on-orbit assembly of large structures, such as next generation science telescope. The project is collaborating with DoD and SMD.

Avionics, Communication, and Navigation

Key projects within this portfolio include the following:

- High Performance Spaceflight Computing (HPSC) is intended to develop a next-generation flight computing system that can improve in-space computing performance to 100 times the computational capacity of current flight processors for the same amount of power, and add unprecedented flexibility to trade among computational performance, energy management, and fault tolerance.

- Distributed Spacecraft Autonomy (DSA) will develop technology demonstrating autonomous decision-making for multi-spacecraft missions and will significantly increase the effectiveness of missions and systems by operating them as a collective rather than individually.

INDUSTRY AND COMMERCE INNOVATION OPPORTUNITY

STMD will stimulate the commercial space industry through collaborative partnerships that foster the technology development required for future NASA, commercial, and government sector capabilities and missions. STMD employs a novel, merit-based competition model to ensure that NASA maintains a crosscutting portfolio that spans a range of technical disciplines and market readiness levels.

ACHIEVEMENTS IN FY 2021

- SPLICE tested the sensors, software, and avionics hardware on Blue Origin's New Shepard suborbital flight test vehicle. Post-flight data performance analysis of the associated subsystems will inform design changes and modifications for the upcoming lunar flight units. Additionally, the Navigation Doppler Light Detection and Ranging (NDL) delivered Engineering Test Units to Astrobotic's and Intuitive Machine's Lunar Lander for demonstration and infusion for lunar precision landing capability.
- Through a partnership with Blue Origin, the Deorbit, Descent, and Landing project successfully completed two suborbital flight tests whose data will verify and validate the navigation system using the Jet Propulsion Laboratory's (JPL) terrain relative navigation in FY 2022.
- MEDA is providing weather measurements, including wind speed and direction, temperature, and humidity. The instrument will also measure the amount and size of dust particles in the Martian atmosphere. Measurements from the MEDA investigation have been utilized by other Mars 2020 investigations, such as MEDLI2, MOXIE, and Mars Helicopter.
- Synthetic Biology returned generation-1 BioNutrient production packs from the ISS containing yeast cultures that have been bioengineered to produce specific nutrients such as beta carotene. These BioNutrient production packs were activated by crewmembers using approved hydration and incubation procedures. The samples were frozen on the ISS and returned on SpaceX-21 for analysis and comparison to control samples, which were grown on Earth.
- ISAAC performed several demonstrations on the ISS to demonstrate module mapping and anomaly detection to validate the initial IVR Technology architecture.
- PRIME completed the integrated interfaces Preliminary Design Review (PDR) and Critical Design Review (CDR). Critical hardware procurements for both the Mass Spectrometer observing lunar operations (MSolo) instruments and The Regolith and Ice Drill for Exploring New Terrain (TRIDENT) drill were completed. Fabrication of both MSolo and TRIDENT were completed in preparation for instrument testing and calibration, mechanism integration and testing, and other high-fidelity validation and verification hardware and avionics testing.

- VSAT awarded contracts to multiple vendors for a nine-month study and conceptual design effort to develop an autonomous deployable and re-deployable lunar solar array capable of providing 10-kilowatts of power.
- Lunar Dust Mitigation, which incorporates active, passive, and operational approaches, is in development and will be demonstrated as payloads on early CLPS missions. Specifically, the EDS project completed the project design review. Furthermore, sample design reviews of experimental materials and coatings will be completed for the CLPS Regolith Adherence Characterization experiment.
- MMPACT completed a successful build and hot fire test of the world's first 3D printed Lunar Landing Pad. The project has completed prototype tests of both laser-melted and molten regolith extrusion construction methods and undertaken characterization of cementations mixtures of lunar regolith simulants and binders (e.g., calcium sulfo-aluminate). Those methods have been confirmed as viable candidates for lunar construction materials and processes.
- Bulk Metallic Glass Gear (BMGG) completed cryogenic testing of new bulk metallic glass flexspline design for strain wave gears technology to enable lunar night operations. BMGG delivered an engineering model and was integrated into the COLDArm Flight Model (FM).
- SAC realized carbon nanotube (CNT) material strength goals, which will permit the mass savings envisioned. This was demonstrated through a parametric finite element model built to assess the impact of CNT properties on structural elements where systems level benefits are most significant.
- Deployable Hopper TP, with Intuitive Machines (IM), completed the CDR.
- LTE/4G communications system, with Nokia, completed the PDR and CDR and completed the fabrication and delivery of the Engineering Development Unit (EDU) for end-to-end integrated testing.
- HPSC released a Request for Proposal and awarded contracts to multiple companies for design studies and evaluated results of radiation testing on 22 nanometer test chips.

WORK IN PROGRESS IN FY 2022

- The TALOS team will complete the thruster design and performance testing and Frontier Aerospace TP will deliver qualified flight thrusters for Astrobotic's Peregrine Lander CLPS mission to Lacus Mortis.
- RAMPT will complete a manufacturing demonstration of a 35,000 pound of force composite overwrap combustion chamber. In addition, new project content for additive manufacturing technology materials will be pursued for high-temperature applications.
- Reactive Additive Manufacturing for Fourth Industrial Revolution Exploration Systems ACO will perform a hot-fire demonstration of a nozzle using a newly patented additive manufacturing material developed by Elementum 3D in partnership with Marshall Space Flight Center (MSFC), Aerojet Rocketdyne, and the Air Force Research Laboratory (AFRL).
- SPLICE will incorporate design changes based on Blue Origin's New Shepard flight tests and complete development and assembly of the Descent Landing Computer (DLC) and Hazard Detection LIDAR (HDL) engineering test units for a suborbital flight on Masten's new Xogdor vehicle.

- Astrobotic TP will deliver an operational Terrain Relative Navigation and Visual Velocimetry sensor product for commercialization capability for lunar and planetary landers.
- SCALPSS will complete assembly of major payload components (Data Storage Unit and camera/mount assemblies). The payload will then perform full functional testing and proceed into environmental testing on flight hardware.
- Honeywell SCOR project will complete the Hydrogen Recovery by Carbon Vapor Deposition brassboard prototype unit. Following successful checkout testing, Honeywell will deliver this unit to NASA for potential future integrated Environmental Control and Life Support Systems testing with a Sabatier system.
- Synthetic Biology will complete development and delivery of a generation-2 BioNutrient production pack that requires much less mass and volume. These updated production packs will include new types of bioengineered micro-organisms that can selectively produce key nutrients and other valuable products. These production packs will be delivered to the ISS to inform the designs of the final version of production packs.
- ISAAC will complete autonomous operation demonstrations on the ISS using IVR for operations without human intervention and incorporate multi-sensor mapping.
- ISM is maturing the design of their additive manufacturing flight system to meet ISS EXPRESS rack requirements.
- LSIC currently has over 1,500 participants from over 600 organizations representing industry, academia, other government agencies, and non-profits from all 50 states and 38 countries. In FY 2022, the Johns Hopkins Applied Physics Laboratory (APL) will provide Technology Maturation Assessments for the six LSII capability areas as the LSII System Integrator. These assessments will incorporate key insights and feedback from the LSIC industry and university members. This ensures NASA's collaborative opportunities and solicitations result in accelerating the development of cutting-edge technologies, while providing the greatest value-proposition for commercial and academic partners across the United States.
- NASA will complete final integrated payload and validation and verification testing of the PRIME hardware to Intuitive Machine's Lunar Lander to be sent to the lunar surface for demonstration on an early CLPS mission.
- The VSAT solar array conceptual design study will conclude, and the project will down-select and award contracts to two vendors to move forward with the detail design, fabrication, and testing.
- Ultra-Fast Proximity Charging TP will complete the Lunar Night Survival Study and PDR for the wireless power transfer system.
- EDS will complete the CDR and System Acceptance Review (SAR)/System Integration Review (SIR) critical milestones, as well as complete the final environmental testing.
- LO-DuSST will complete Ceramic Coatings down-selection for wear resistant coatings. The project will also complete the plasma dust removal testing that will provide a TRL4 validation of dust removal technology.
- ISRU Pilot Excavator is developing subsystem prototypes and demonstrating them in a simulated lunar environment.

- MMPACT will mature the materials and technology necessary for construction operations. The team will down-select materials and focus development on prototype hardware to test in simulated lunar environment conditions.
- BMGG will complete cryogenic testing of the planetary gearmotor. The project will also evaluate alternate bulk metallic glass alloys for use in strain wave gears to improve life durability.
- Engineering Model (EM) for the COLDArm system (consisting of Robotic Arm, Motor Controllers, Avionics, and End Effector) will complete testing with a ground demonstration at cryogenic temperatures in preparation for a lunar surface technology demonstration.
- Space Science and Technology Evaluation Facility TP will complete the Concept Design Review and PDR.
- SAC is developing scaled-up composite processes using CNT that will yield structures demonstrating achievement of increased tensile, toughness, and extreme environmental properties above the current state-of-the-art composite materials. Those applications include: entry, descent, and landing systems; hypersonic vehicles; and propulsion systems.
- PASS will accomplish a hardware demonstration of autonomous robotic assembly of three foundational tri-truss structures to validate integrated hardware/software (autonomous planning and control) algorithms. The demonstration will enable creation of high-fidelity analytical models by correlating measured joint load and deflection data.
- CADRE will complete the hardware and software design of the guidance, navigation, and control (GNC) and communication subsystems, and complete build of six Rover Engineering Models (EMs). The project will also demonstrate CADRE Multi-Agent Autonomy, including multi-rover formation and exploration drives (while processing of shared data), in a ground demonstration at JPL.
- Deployable Hopper TP and Nokia 4G/wireless TP will deliver and integrate flight hardware on Intuitive Machines Nova-C Lander for integration into SpaceX Falcon 9 launch vehicle.
- HPSC will continue radiation tolerance testing and will evaluate the results of the design studies to award a contract to the industry partners to develop and produce a radiation tolerant chip with an order of magnitude increase in processing capability.
- DSA will demonstrate autonomous decision-making on multiple spacecraft as part of Small Spacecraft Technology's STARLING mission. The project will simulate a mission of 100 spacecraft in an autonomous multiple spacecraft operation.
- The high-TRL LIDAR will complete the design review in FY 2022 to support proceeding with the fabrication of the Main Electronics Box (MEB), which will also be incorporated into the SMD Dragonfly mission.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

- Formulate a plan for the OSAM consortium in the remainder of FY 2022 and begin implementation in FY 2023.
- Continue high-priority manufacturing, space transportation, and landing technologies to support industry and NASA:

- RAAMBO project will begin initial development, trials, and simulations of refractory alloys for additive manufacturing. The project will advance powder and process development, define printing parameters, characterize heat treatment properties, and determine inspection methods.
- CTE-TDEA will demonstrate high-reliability thermoplastics joining processes for future applications as well as complete material characterization and develop a material database.
- TALOS project will complete development testing of the Deep Space Variant thruster.
- SAC will incorporate lessons learned from CNT composite fabrication process development and then scale the process to accelerate composite production for CNT structural applications. This will advance the manufacturing process from a Manufacturing Readiness Level 3 at the project inception to Manufacturing Readiness Level 6 at the end of the project.
- SPLICE will complete system level testing and deliver hardware for Masten Xogdor flight.

- Develop crosscutting technologies to support science, human space exploration, other government agencies, and industry needs (e.g., advanced spaceflight computing, advanced manufacturing, and autonomous systems and robotics):
  - Synthetic Biology will deliver the generation-3 BioNutrient production pack designs that can produce multiple nutrient types at the same time. In addition, the Synthetic Biology project will deliver an electrochemical system that can directly convert energy and CO2 into selected products such as formic acid that can be used as growth media for multiple ISRU based biomanufacturing processes.
  - HPSC chip development and production will continue, and the project will design, fabricate, and qualify a single-board computer to demonstrate the capabilities of the HPSC chip.
  - PASS will demonstrate and measure performance of assembly operations for modules with electrical connections during autonomous, end-to-end, precision assembly.
  - DSA will complete the planned on-orbit experiments and report out on the capability development.
- Utilize NASA’s CLPS program to deliver payloads and experiments to the Lunar surface:
  - CLPS will deliver PRIME, Deployable Lunar Hopper, and 4G/LTE Proximity Communications demonstrations to the Lunar surface on the Intuitive Machines-2 mission.
  - CADRE will complete fabrication of the flight system (Rovers, Base Station, and Deployers), including testing and verifying that the hardware and software meet flight requirements. The project will deliver the CADRE system for integration into the Intuitive Machines Nova-C lander as part of a CLPS mission planned for launch in 2024.
  - PSI Mini Suite will complete a PDR in preparation for the lunar flight demonstration in 2025.
  - SCALPSS and EDS will be delivered for integration with the Firefly Aerospace Blue Ghost lander mission currently schedule for launch in 2023.
  - LO-DuSST will complete ground testing in a vacuum with lunar simulant of the electrostatic/repulsion system, develop a ceramic coated lander leg test article, report on scalability of topographical modification techniques and complete the assembly and validation of the solar array dust mitigation test system. The project will also complete the program Technical Assessment Periodic Review (TAPR).

- Develop surface excavation and construction technologies to promote sustainable habitation on the Lunar surface:
    - COLDArm and BMGG will complete functionality and environmental testing and will be packaged for shipping to the lander provider for integration on a CLPS mission planned for launch in 2024.
    - MMPACT will continue development of landing pad and habitat architectural designs while developing an engineering unit for a future lunar demonstration.
    - ISRU Pilot Excavator will complete a full-system excavation ground demonstration and reduce operational risk by testing lunar soil flow in simulated lunar gravity on a Blue Origin demonstration flight.
    - CHIPS will complete the integrated chemical heat source and power converter breadboard prototype system. This system will be operated to demonstrate generation of at least 30 watts of electrical power and 90 watts of thermal energy for at least 72 hours of continuous operation.
    - VSAT vendors will continue development of a prototype lunar system and VSAT will complete the systems design and fabrication of the prototypes and plan for testing to be completed in FY 2024 maturing the VSAT system to TRL 6.

ACQUISITION STRATEGY

These critical technology projects are defined as part of the strategic framework and capabilities, through requirements determined by the Federated Team, and through selection by STMD's annual Strategic Technology Architecture Roundtable (STAR) process. In addition, STMD embraces competition and external partnerships; as such, some of the technologies are selected through the annual TP, ACO, and other NASA solicitations.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
HPSC	TBD	TBD
VSAT	TBD	TBD
Deployable Hopper Tipping Point	Intuitive Machines	Houston, TX
LTE/4G Communications Tipping Point	Nokia of America	Sunnyvale, CA
Lunar Surface Innovation Initiative	Johns Hopkins APL	Laurel, MD

TECHNOLOGY DEMONSTRATION

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Solar Electric Propulsion (SEP)	26.2	24.2	**18.5**	15.9	17.8	5.8	3.8
OSAM-1	227.0	227.0	**227.0**	227.0	121.8	25.4	0.0
Small Spacecraft, Flight Opportunities & Other Tech Demo	275.2	250.6	**279.9**	292.5	406.0	524.8	562.8
Total Budget	**528.4**	**501.8**	**525.4**	**535.4**	**545.6**	**556.0**	**566.6**
Change from FY 2022 Budget Request			**23.6**				
Percent change from FY 2022 Budget Request			**4.7%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The Laser Communications Relay Demonstration (LCRD) mission launched in December 2021 as a hosted payload with the United States Space Force Space Test Program 3 mission.

The Technology Demonstration portfolio includes the Technology Demonstration Missions, Small Spacecraft Technology, and Flight Opportunities.

The Technology Demonstration Missions (TDM) program conducts both ground-based testing and space flight demonstrations. Ground-based testing is performed to advance technologies from component validation in a relevant environment to system model or prototype demonstration in a relevant or operational environment. TDM's goal is to further advance system level technologies through the completion of space flight demonstrations and transition these new capabilities for use by NASA missions, industry, and other Government agencies.

The TDM portfolio include projects supporting NASA missions, the commercial space sector, and other Government agencies. Technology investments include high-power solar electric propulsion for the Artemis Power and Propulsion Element, precision lunar landing and hazard avoidance, cryogenic fluid management, in-situ resource utilization and sustainable lunar surface power, advanced communications and navigation demonstrations, and on-orbit servicing, assembly, and manufacturing.

Commercial sector collaborations continue to be used to enable NASA to share the risk and financial interest with private industry and better leverage Government investments. For example, through NASA’s fifth Tipping Point Technologies solicitation and selection process, cryogenic fluid management technologies will be matured through in-space demonstrations and lead to the implementation of these technologies in operational missions. NASA and industry partners will develop and test numerous cryogenic storage, transfer, and mass gauging technologies to enable more efficient usage of cryogenic fluids which could contribute to several applications including lander systems, ISRU technologies,

TECHNOLOGY DEMONSTRATION

in-space chemical propulsion systems, and nuclear thermal propulsion. Additionally, entry, descent, and landing technologies will provide the capability to return large payloads to Earth, enabling the re-use of space systems and, potentially, the affordable return of objects manufactured in space to Earth.

The Technology Demonstration portfolio also supports the Flight Opportunities and Small Spacecraft programs' rapid development and demonstration of technologies through partnership with U.S. industry for suborbital flight testing and small spacecraft missions. These programs leverage agile spacecraft platforms and responsive launch capabilities to increase the pace of space exploration, scientific discovery, and the expansion of space commerce. These emerging capabilities have the potential to enable new mission architectures, enhance conventional missions, and promote development and deployment on faster timelines. The programs partner with U.S. industry and academia to target technology gaps that market forces would not otherwise fill. The two programs address the advancement of technologies that support National efforts in cislunar space, breakthrough observing capabilities for Earth and beyond, and other capabilities that ensure National leadership in space and help the commercial space industry grow.

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

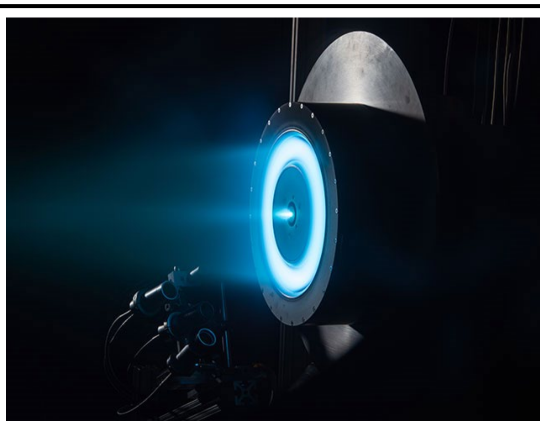
FY 2023 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027	BTC	Total
Formulation	179.2	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	179.2
Development/Implementation	67.0	32.0	30.1	**20.9**	21.6	20.2	5.8	3.8	1.8	203.2
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2022 MPAR LCC Estimate	**246.2**	**32.0**	**30.1**	**20.9**	**21.6**	**20.2**	**5.8**	**3.8**	**1.8**	**382.4**
Total Budget	**246.2**	**26.2**	**24.2**	**18.5**	**15.9**	**17.8**	**5.8**	**3.8**	**0.0**	**358.4**
Change from FY 2022 Budget Request				**-5.7**						
Percent change from FY 2022 Budget Request				**-23.6%**						

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The FY 2022 MPAR LCC Estimate for SEP reflects the total LCC reported by NASA in March 2022. The requested budget authority is the project's current budget requirements and is inclusive of Space Technology only.



Solar Electric Propulsion technology development unit hall thruster is shown here in testing. The project will be qualifying a 12-kilowatt thruster that will be demonstrated on the Lunar Gateway Power and Propulsion Element.

PROJECT PURPOSE

Led by the Glenn Research Center (GRC), NASA will continue the development of Solar Electric Propulsion (SEP) with higher-power, longer-life thrusters. The first operational demonstration of this 12-kilowatt (kW) thruster will be as the primary propulsion element to place the Lunar Gateway into the highly elliptical lunar orbit. This demonstration will provide NASA with experience in electric propulsion maneuvers in the family of orbits around the Moon and demonstrate operational approaches and interfaces with visiting crew and robotic vehicles. SEP will also enable more efficient orbit transfer of spacecraft and accommodate the increasing power demands for Government and commercial satellites.

The SEP thrusters will not only meet the objectives of future NASA exploration purposes, but also support the growing demand for increased electric propulsion performance for commercial satellites. This development will be integrated with previous NASA

Formulation	Development	Operations

advancements in deployable solar array structures. These arrays, with half of the mass and one-third of the packaging volume compared to state-of-the-art solar arrays, have already been incorporated into commercial satellite product lines enabling greater payload mass.

EXPLANATION OF MAJOR CHANGES IN FY 2023

NASA informed Congress by letter dated July 15, 2021 that Solar Electric Propulsion (SEP) experienced a significant cost overrun and schedule delay. NASA addressed the root causes of the overrun and delays, and subsequently established a new estimate for the project with a revised budget and schedule. On March 10, 2022, NASA transmitted the final SEP Project Cost and Schedule Analysis Report pursuant to Section 103(d) of the NASA Authorization Act of 2005 (P.L. 109-155). NASA's detailed report included a project overview and scope, discussion of development cost and schedule growth, an analysis of alternatives, and a new cost and schedule estimate.

Pursuant to Section 103(e) of P.L. 109-155, this budget request establishes a new baseline for SEP. The detailed discussion of SEP included in this budget request constitutes NASA's response to the requirements of Section 103(e) of P.L. 109-155 for a New Baseline Report for SEP. This new baseline is consistent with NASA's prior notifications and reflects a revised life cycle cost estimate of $382.4 million. The new baseline plan also includes a revised development schedule, with launch in October 2028.

PROJECT PARAMETERS

The goal of the project is to qualify a 12-kW solar electric propulsion thruster to be used as primary propulsion for a spaceflight demonstration. Objectives include:

- Qualify high-power SEP thruster technology for use in relevant space environments through demonstration of continuous long-term operation of the system sufficient to characterize and predict the performance and lifetime of the system;
- Qualify electric propulsion thruster for extended operations in deep space; and
- Provide Government Furnished Equipment plasma diagnostics to characterize high-power SEP performance and space vehicle interactions on U.S. spaceflight missions.

ACHIEVEMENTS IN FY 2021

The SEP contract with Aerojet Rocketdyne was renegotiated, reflecting development of electric propulsion thrusters going through qualification only. A delta KDP-C was held in May 2021 to update the project's Level 1 requirements to develop and qualify an advanced 12-kW electric propulsion thruster applicable to human/robotic exploration and commercial spaceflight missions including the Power and Propulsion Element (PPE). A project re-plan was approved at the delta KDP-C and addressed contractor performance, COVID-19 impacts, the PPE procurement strategy, schedule, and mission requirements. This re-plan included adjustments to the Gateway PPE requirements and is aligned to the Gateway PPE mission needs.

SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

The project completed wear testing on the development thruster unit for various PPE throttle and operations conditions. Other component tests have continued the development of ancillary subsystems that make up the thruster assembly. The cathode component has recently undergone vibration and shock tests to verify the design prior to Critical Design Review (CDR).

The project conducted a Preliminary Design Review (PDR) on the Plasma Diagnostics Package (PDP), leading to the hardware build of the Thruster Probe Assembly and Main Electronics Package engineering development units.

WORK IN PROGRESS IN FY 2022

The SEP project is working toward completing the CDR for the electric propulsion thrusters in March 2022.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

The SEP project expects to receive the first qualification thruster from Aerojet Rocketdyne at the beginning of the first quarter of FY 2023. The PDP is expected to be delivered to PPE by Spring 2023.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2023 PB Request
Formulation Authorization	Mar 2015 (as part of Asteroid Redirect Robotic Mission [ARRM])	Mar 2015 (as part of ARRM)
KDP-A	Mar 2015 (as part of ARRM)	Mar 2015 (as part of ARRM)
Preliminary Design Review	Aug 2017	Aug 2017
KDP-C	Oct 2019	Oct 2019
Delta KDP-C	-	May 2021
CDR	Mar 2022	Mar 2022
New Baseline*	Mar 2022	Mar 2022
Deliver Plasma Diagnostics Package for Lunar Gateway for Integration	Spring 2023	Spring 2023
Advanced Electric Propulsion System Life Qualification Test Report	Oct 2028	Oct 2028

**Pursuant to Section 103(e) of P.L. 109-155, this budget request establishes a new baseline for SEP. The original SEP baseline in 2020 had a 30 percent development cost increase and a 46-month schedule increase.*

SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2022	203.2	70%	2022	203.2	0	Electric Propulsion Thruster Life Qual Test Report	Oct 2028	Oct 2028	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Pursuant to Section 103(e) of P.L. 109-155, this budget request establishes a new baseline for SEP. The original SEP baseline in 2020 had a 30 percent development cost increase and a 46-month schedule increase.

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**203.2**	**203.2**	**0.0**
Science/Technology	159.7	159.7	0.0
Other Direct Project Costs	43.5	43.5	0.0

SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Program Management	Manages Aerojet Rocketdyne contract, thruster development life testing and qualification testing, and Plasma Diagnostics Package	Lead Center: GRC Performing Center(s): GRC Cost Share Partner(s): N/A	N/A
Thruster Development	Thruster development and life qualification testing support	Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Thruster Design	Thruster design and qualification	Provider: Aerojet Rocketdyne Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

Acquisition Strategy

All major acquisitions are in place.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Advanced Electric Propulsion System Contract	Aerojet Rocketdyne	Redmond, WA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
PDR	IRT	Aug 2017	Assess/approve preliminary design	Passed	CDR
CDR	SRB	Mar 2022	Assess/approve final design	TBD	Qualification System Acceptance Review (QSAR)-1

SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
QSAR-1	SRB	Jun 2024	Assess/approve environmental test results for Qualification Module-1	TBD	QSAR-2
QSAR-2	SRB	Jun 2025	Assess/accept preliminary life test data for Qualification Module-2	TBD	N/A

OSAM-1

Formulation	Development	Operations

FY 2023 Budget

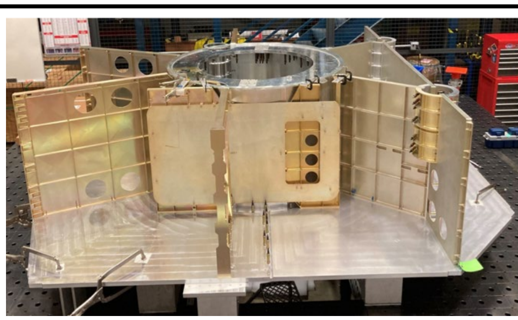
Budget Authority (in $ millions)	Prior	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027	BTC	Total
Formulation	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
Development/Implementation	0.0	227.0	227.2	**227.2**	177.4	43.2	0.0	0.0	0.0	902.0
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	39.6	25.4	0.0	0.0	65.0
2022 MPAR LCC Estimate	**0.0**	**227.0**	**227.2**	**227.2**	**177.4**	**82.8**	**25.4**	**0.0**	**0.0**	**967.0**
Total Budget	**813.0**	**227.0**	**227.0**	**227.0**	**227.0**	**121.8**	**25.4**	**0.0**	**0.0**	**1,868.1**
Change from FY 2022 Budget Request				**0.0**						
Percent change from FY 2022 Budget Request				**0.0%**						

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The 2022 MPAR LCC Estimate reflects the Fiscal Year 2022 Quarter 1 Financial Report, which is current as of December 2021. The requested budget authority is the project's current budget requirements which have seen programmatic changes approved by NASA since December 2021.

An initial notification has been sent to Congress stating OSAM-1 would exceed its cost/schedule thresholds. A review is currently underway to determine the complete impact on the project.



Shown here is the OSAM-1 Servicing Payload Flight Structure Assembly at Goddard Space Flight Center.

PROJECT PURPOSE

On-Orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1) is a full-scale technology demonstration mission to advance robotic on-orbit satellite servicing, assembly, and manufacturing technologies to operational status. This will be accomplished via the on-orbit refueling of a U.S. Government satellite in low-Earth orbit (LEO), followed by an assembly and manufacturing demonstration. The SPace Infrastructure DExterous Robot (SPIDER), which is a payload developed under a NASA Space Technology Mission Directorate (STMD) Tipping Point procurement to advance technologies needed for an in-space robotic manufacturing and assembly capability, is part of this mission and will robotically assemble a communications antenna and manufacture a structural beam in orbit.

OSAM-1

Formulation	Development	Operations

The technologies developed and demonstrated by OSAM-1 have direct applicability to future space endeavors by providing capture technologies for spacecraft, refueling and fluid transfer capabilities, the ability to relocate a space asset, conduct unplanned repairs and planned maintenance of client spacecraft, and the capability to assemble and manufacture structures. As part of its autonomous operations demonstration, NASA will assemble multiple antenna elements into one large antenna reflector using SPIDER. This revolutionary process allows satellites, telescopes, and other systems to use larger and more powerful components that would not fit into a standard rocket fairing when assembled on the ground or without complex folding mechanisms. The OSAM-1 technologies could enable entirely new architectures and space infrastructure for a wide range of Government and commercial missions. The project is actively transferring technologies to the U.S. commercial sector in an effort to jump-start new industries such as a robust on-orbit servicing, assembly, and manufacturing (OSAM) market.

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

PROJECT PARAMETERS

With application to both commercial and NASA operations, OSAM-1 will demonstrate satellite servicing capabilities and in-space assembly and manufacturing capabilities. Objectives include:

- Autonomous, real-time relative navigation system, including sensors, algorithms, and processors integrate together allowing the spacecraft to inspect and rendezvous safely with its client;
- Servicing Avionics control the spacecraft rendezvous and robotic tasks;
- Autonomous capture of client satellite;
- Dexterous Robotic Arms provide maneuverable arms for executing servicing assignments using telerobotics, including software;
- Advanced Tool Drive and Tools are multifunction tools for executing the servicing tasks;
- Propellant Transfer System delivers measured amounts of fuel to the client at the right temperature, pressure, and rate;
- Relocation of client satellite;
- On-orbit assembly of an antenna; and
- On-orbit manufacture of a thermally stable and structural precision beam.

ACHIEVEMENTS IN FY 2021

OSAM-1 continued the development of the spacecraft bus and completed the spacecraft propulsion module integration. Seven subsystem critical design reviews were successfully conducted. SPIDER held its Critical Design Review (CDR) in February 2021 and initiated payload and integration activities. The project also completed construction of the Mission Operations Center at Goddard Space Flight Center (GSFC). Psionic LLC was awarded a non-exclusive, commercial license for the OSAM-1 Kodiak Lidar to enhance their capabilities for precision navigation.

OSAM-1

Formulation	Development	Operations

WORK IN PROGRESS IN FY 2022

The project completed its replan efforts to incorporate COVID-19 impacts. A breach notification was sent to Congress on February 14, 2022. OSAM-1 successfully completed an integrated flight demonstration mission CDR in February 2022 and the Servicing Payload integration will commence. The spacecraft mechanical and electrical integration is in progress and the spacecraft bus and the SPIDER pallet will be integrated in FY 2022. The project will hold its Systems Integration Review (SIR) and the space vehicle Integration and Testing activities will commence at GSFC. OSAM-1 will continue to leverage Technology Transfer mechanisms and pursue partnerships with interested U.S. companies through Space Act Agreements to transfer knowledge and capabilities to industry. Finally, the project's Key Decision Point-D (KDP-D) will be held no earlier than August 2022.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

In FY 2023, critical hardware work will continue with the robot subsystem, and the SPIDER and Servicing Payloads will be integrated onto the MAXAR-provided space vehicle in preparation for environmental testing in FY 2024.

SCHEDULE COMMITMENTS/KEY MILESTONES*

Milestone	Confirmation Baseline Date	FY 2023 PB Request
KDP-C	May 2020	May 2020
CDR	Sep 2021	Feb 2022
System Integration Review	Jul 2022	TBD
KDP-D	Aug 2022	TBD
Operational Readiness Review	Sep 2025	TBD
KDP-E	Sep 2025	TBD
Launch Readiness Review	Sep 2025	TBD
Launch	Sep 2025	TBD

** An initial notification has been sent to Congress stating OSAM-1 would exceed its cost/schedule thresholds. A review is currently underway to determine the complete impact on the project.*

OSAM-1

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2021	974.4	>70%	2022	TBD*	TBD*	Launch	Sep 2025	TBD*	TBD*

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

** An initial notification has been sent to Congress stating OSAM-1 would exceed its cost/schedule thresholds. A review is currently underway to determine the complete impact on the project.*

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)*	Change from Base Year Estimate ($M)*
TOTAL:	**974.4**	**TBD**	**TBD**
Aircraft/Spacecraft	53.1	TBD	TBD
Payloads	338.5	TBD	TBD
Systems I&T	70.9	TBD	TBD
Launch Vehicle	83.0	TBD	TBD
Ground Systems	32.6	TBD	TBD
Science/Technology	0	TBD	TBD
Other Direct Project Costs	396.3	TBD	TBD

** An initial notification has been sent to Congress stating OSAM-1 would exceed its cost/schedule thresholds. A review is currently underway to determine the complete impact on the project.*

OSAM-1

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Propellant Transfer Subsystem (PTS)	Develop, test, and build of propellant transfer system.	Provider: N/A Lead Center: Kennedy Space Center (KSC) Performing Center(s): KSC, GSFC Cost Share Partner(s): N/A	N/A
Spacecraft Bus	Build and deliver a spacecraft bus to carry the payload.	Provider: Maxar Technologies Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Program Management	Project management, payload development and delivery, and mission integration.	Provider: N/A Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
SPIDER	Build and deliver the SPIDER payload.	Provider: Maxar Technologies Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): Langley Research Center (LARC)	N/A

Acquisition Strategy

Element/Component	Acquisition Method	Developer
Robot Arm	In-house development	GSFC with Maxar Technologies as major sub
Rendezvous and Proximity Ops Cameras	NASA Competition	Neptec Design Group
LIDAR	In-house development	N/A
Vision Sensor Subsystem Cameras	NASA Competition	Malin Space Science Systems
Propellant Transfer System	Competition/Justification for Other than Full and Open Competition	Valve Tech, FHM Aerospace, Vacuum and Air Components Company of America, Hoffer
Motors Arm, next generation Tool Drive, Pan/Tilt Unit (camera), Motorized Zoom Lenses	Omnibus Multidiscipline Engineering Services contract	CDA InterCorp, Triumph, Honeybee Robotics

OSAM-1

Formulation	Development	Operations

Element/Component	Acquisition Method	Developer
SPIDER	Competitively selected via STMD Tipping Point solicitation	Maxar Technologies

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Build and delivery of spacecraft bus	Maxar Technologies	Palo Alto, CA
Build and delivery of SPIDER payload	Maxar Technologies	Palo Alto, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Mission Concept Review (MCR)	N/A	Apr 2016	Affirm mission need, examine proposed mission objectives, and validate the concept for meeting those objectives.	Passed	SRR
System Requirements Review (SRR)	Standing Review Board (SRB)	Oct 2016	Examine the functional and performance requirements and the preliminary project plan. Ensure the requirements and selected concept will satisfy the mission.	Passed	PDR
JCL	Tecolote	Nov 2017	Determine realistic 50/70 percent confidence level on reference budget and schedule.	N/A	PDR
Preliminary Design Review (PDR)	SRB	Nov 2017	Demonstrate the preliminary design meets all system requirements with acceptable risk and within cost and schedule constraints.	Passed	CDR
Critical Design Review (CDR)	SRB	Feb 2022	Demonstrate the maturity of the design is appropriate to support proceeding with full-scale fabrication, assembly, integration, and test.	Passed	SIR

OSAM-1

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
System Integration Review (SIR)	SRB	TBD	Evaluate the readiness of the program to begin system Integration and Test with acceptable risk and within cost and schedule constraints.	TBD	ORR
Operational Readiness Review (ORR)	SRB	TBD	Evaluate the readiness of the program to operate the flight system and associated ground systems in compliance with program requirements and constraints during the operations phase.	TBD	N/A

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Laser Comm Relay Demo (LCRD)	15.1	0.0	**0.0**	0.0	0.0	0.0	0.0
Small Spacecraft Technology (SST)	42.2	46.2	**55.0**	56.1	57.2	58.4	59.5
Flight Opportunities Program (FOP)	27.0	25.0	**25.0**	25.0	25.0	25.0	25.0
TDM Cryogenic Fluid Management (CFM)	60.1	84.9	**124.6**	101.2	109.1	126.6	146.4
TDM Space Nuclear Technologies Portfolio	57.9	34.0	**45.0**	101.0	201.7	273.3	273.3
TDM LeO Flight Test of an Inflatable Dec	20.6	13.0	**2.4**	0.0	0.0	0.0	0.0
TDM Mars Oxygen ISRU Experiment (MOXIE)	2.3	1.9	**0.9**	0.0	0.0	0.0	0.0
Archinaut (OSAM-2)	23.2	14.2	**10.8**	0.0	0.0	0.0	0.0
TDM Deep Space Optical Comm (DSOC)	18.0	6.3	**2.0**	0.1	0.0	0.0	0.0
TDM Deep Space Atomic Clock (DSAC)	1.9	13.8	**0.0**	0.0	0.0	0.0	0.0
Tech Demo Management and Integration	6.4	10.8	**14.3**	9.2	13.0	41.5	58.5
Tech Demo Selected ACO/TP	0.6	0.5	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**275.2**	**250.6**	**279.9**	**292.5**	**406.0**	**524.8**	**562.8**
Change from FY 2022 Budget Request			**29.3**				
Percent change from FY 2022 Budget Request			**11.7%**				

Shown here is the Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) spacecraft in handling fixture. CAPSTONE will demonstrate entry into and operations in a near rectilinear halo orbit around the Moon, as well as spacecraft-to-spacecraft navigation.

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

SMALL SPACECRAFT TECHNOLOGY

The Small Spacecraft Technology program expands U.S. ability to execute unique missions through rapid development and demonstration of capabilities for small spacecraft applicable to exploration, science, and the commercial space industry. Through targeted development and frequent in-space testing, the program enables execution of missions at a much lower cost than previously possible, substantially reduces the time required to develop spacecraft, enables new mission architectures using small spacecraft, expands the reach of small spacecraft to new destinations and challenging new environments, and enables the augmentation of existing assets and future missions with supporting small spacecraft.

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

Small Spacecraft Technology Demonstration Missions of Opportunity

The fast pace of innovation, changing geopolitical and market environments, and 24-month development target for Small Spacecraft Technology missions present challenges that are not easily addressed by traditional multi-year budgeting and acquisition cycles. The budget request for FY 2023 includes pursuing a mission-of-opportunity-based approach that will improve the ability to work with the entrepreneurial space industry and increase the agility and effectiveness of the Small Spacecraft Technology portfolio. Initial technology demonstration missions of opportunity will use industry partnerships, challenges, SBIR, and other methods to target needs identified by the Science Mission Directorate (SMD), commercial industry, and other U.S. Government operators of small spacecraft.

In addition to initiating new technology demonstrations of opportunity, the Small Spacecraft Technology program anticipates reaching initial launch readiness for 15 current missions between 2022 and 2023, including the following:

Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE)

CAPSTONE is a rapid lunar demonstration leveraging American small businesses that was awarded at the end of 2019. Over the course of 2020, Advanced Space LLC, Tyvak Nano-Satellite Systems, Inc., and Stellar Exploration, Inc. completed critical reviews and began assembly and ground testing of the microwave oven-sized 12U CubeSat that will serve as the first spacecraft to test the lunar near rectilinear halo orbit (NRHO) targeted for the Artemis missions and Gateway. In 2021, spacecraft Test Readiness Reviews and Mission Operational Readiness Tests were completed. Several early technology transitions have occurred, including use of the propulsion system developed for CAPSTONE on a commercial telecom mission. As a precursor for the Artemis Campaign, CAPSTONE will help reduce risk for future spacecraft by validating innovative navigation technologies and verifying the dynamics of the NRHO. CAPSTONE represents a rapid lunar flight demonstration and is scheduled to launch in early 2022 aboard a Rocket Lab Electron rocket, which will be the first mission beyond Earth for that launch vehicle.

For more information, go to: https://www.nasa.gov/directorates/spacetech/small_spacecraft/capstone

Lunar Flashlight

The Lunar Flashlight mission, developed and managed by JPL with support from Georgia Tech, MSFC, and multiple small businesses, will precede human explorers to the Moon to prospect for water resources that can be extracted to support sustainable exploration and commercial lunar activity. The CubeSat will use near-infrared lasers to shine light into permanently shadowed craters at the lunar south pole, while the onboard spectrometer measures surface reflection and composition to map water ice deposits and volatiles. Originally intended to launch with the Artemis I mission, completion of the spacecraft was delayed due to COVID-19 and commercial lunar launch opportunities are currently being explored for 2022.

For more information, go to:
https://www.nasa.gov/directorates/spacetech/small_spacecraft/What_is_Lunar_Flashlight

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

Starling

Starling is a technology demonstration mission that will deploy a formation of four CubeSats to test multiple distributed mission technologies. Distributed systems of small spacecraft can responsively provide cost-effective multi-point science data collection, communications, monitoring, and inspection infrastructure in Earth orbit to support Artemis and other exploration missions. The Starling mission will: test network communication protocols with the goal of demonstrating a network that is resistant to multiple lost nodes and scalable to hundreds of spacecrafts; test formation flight control algorithms; test relative navigation methods that do not rely on Earth-centric resources (e.g., GPS); and demonstrate autonomous reactive operations that allow the distributed mission to reconfigure in response to external sensor data. An extended mission in work for Starling will develop and demonstrate both the technology and operational protocols for autonomous maneuvering and coordination between spacecraft constellations from different operators. These new protocols will help mitigate future orbital debris concerns. The Starling mission includes contributions from Stanford University, Blue Canyon Technologies, Emergent Space Technologies, CesiumAstro, and NASA's Game Changing Development program.

For more information, go to: https://www.nasa.gov/directorates/spacetech/small_spacecraft/starling/

Recent and Planned Achievements

The Small Spacecraft Technology program launched four orbital missions and one suborbital mission in FY 2021, including:

- The Pathfinder Technology Demonstrator (PTD) 1 mission launched on January 24, 2021 and completed on-orbit testing of the Tethers Unlimited Inc. (TUI) HYDROS, a water-based propulsion system. The development of this thruster was supported through a Tipping Point opportunity between TUI (now AMERGINT Technologies Inc.) and NASA. The HYDROS is intended to provide safe, high-performance propulsion for multi-manifest payloads. The propulsion system launched with only liquid water as the propellant and then used electrolysis to split the water into gaseous hydrogen and oxygen to fuel the bipropellant thruster once in orbit. The overall PTD series will test the operation of a variety of novel CubeSat technologies in orbit, providing significant enhancements to the performance of these small and effective spacecraft. The spacecraft, payload integration, and operations are provided under a commercial contract with Tyvak Nano-Satellite System, Inc. With the completion of the HYDROS testing, the PTD-1 spacecraft is being turned over to Lawrence Livermore National Laboratory for a non-propulsion related extended mission.
- The V-R3x group of three low-power, low-cost 1U spacecraft launched on January 24, 2021. V-R3x was a collaboration with Stanford University and Carnegie Melon University to demonstrate autonomous networking and radio navigation processes in early 2021 that are key to reducing heavy reliance on ground-based infrastructure and increasing the autonomy of distributed missions with multiple spacecraft. V-R3x was the first mission managed within the rapid development and demonstration Payload Accelerator for CubeSat Endeavors (PACE) project. PACE is jointly funded with the Flight Opportunities program to promote a unique approach that combines suborbital flight testing opportunities with orbital testing.

  For more information, go to: https://www.nasa.gov/ames/pace

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

- A Tipping Point demonstration of the Accion Systems' Tile Ionic Liquid Electrospray (TILE) propulsion system launched on June 30, 2021. The extremely compact TILE system, which is modular and uses non-volatile ionic salt propellant, was recently selected for a commercial Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA) class Orbital Maneuvering Vehicle. The ongoing Tipping Point orbital demonstration successfully tested the performance of the TILE on a commercially operated CubeSat.

Fifteen small spacecraft missions, currently under development in FY 2022, are projected to launch in the 2022-2023 timeframe, including the following:

- The CAPSTONE mission is planned to launch no earlier than March 2022 from Rocket Lab USA's launch site in New Zealand.
- The Starling distributed spacecraft demonstration mission will launch no earlier than June 2022 on a Venture Class Launch Services 2 launch with Firefly Aerospace.
- The PTD-3 mission will launch aboard a commercial SpaceX flight in mid-2022. The mission will demonstrate the MIT Lincoln Laboratory TeraByte InfraRed Delivery (TBIRD) optical communication system. The TBIRD was funded by NASA’s Space Communications and Navigation Program (SCaN) and is intended to achieve an unprecedented 200 gigabit per second data downlink rate. This will be a thousand-fold increase over the prior state-of-the-art CubeSat optical downlink demonstrated by the Small Spacecraft Technology Optical Communications and Sensor Demonstration mission.

FLIGHT OPPORTUNITIES PROGRAM

The Flight Opportunities program rapidly demonstrates technologies for space exploration, discovery, and the expansion of space commerce through suborbital testing with industry flight providers. The program matures capabilities needed for NASA missions and strategically invests in the growth of the U.S. commercial spaceflight industry. These flight demonstrations take technologies from ground-based laboratories into relevant environments to increase technology readiness and validate feasibility, while reducing the costs and technical risks of future missions. Awards and agreements for flight demonstrations are open to researchers from industry, academia, non-profit research institutes, NASA, and other Government organizations. These investments help advance technologies of interest to NASA by leveraging the capabilities of commercial flight providers and expanding space-based applications and commerce.

In FY 2021, the Flight Opportunities program enabled 84 tests of payloads on commercial suborbital flight, including nine rocket-powered vehicle flights, nine high-altitude balloon flights, and 14 parabolic aircraft flights. U.S. commercial vendors providing flight services in FY 2021 included: AM0CAL, Blue Origin, Masten Space Systems, Raven Aerostar, Stratodynamics, UP Aerospace, Virgin Galactic, World View, and Zero Gravity Corporation. The capabilities of these flight providers were used to test technologies that will enable long-duration exploration missions, advance space-based manufacturing capabilities, and further our understanding of the climate models on Earth as well as other planets. These flight tests help increase the pace at which technologies can advance to the point where they address critical gaps for both NASA and the commercial spaceflight industry and can be infused into missions.

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

Recent and Planned Achievements

In FY 2021, Flight Opportunities launched the NASA TechLeap Prize to increase the speed with which impactful technologies can be identified and tested on suborbital flights. TechLeap Prize will also increase access to flight tests for small and entrepreneurial organizations. In September 2021, just fourteen weeks after the launch of this prize-based competition, three winners were named in the first challenge, the Autonomous Observation Challenge No. 1. The winning teams were each awarded $200,000 and have the potential to win up to an additional $300,000 during the development of their payloads. Flight Opportunities intends to provide a suborbital flight test to each team that successfully develops their payload within eight months. In comparison, preparation of similar payloads can often take 18 months or more.

Flight Opportunities also launched the NASA TechRise Student Challenge in FY 2021. The hands-on competition, which received nearly 600 applications from more than 40 states and territories, invited students in grades 6-12 to submit ideas for experiments related to areas including climate research, remote-sensing, and space exploration to fly aboard a suborbital rocket or high-altitude balloon. The 57 winning teams from across the U.S. were announced on January 21, 2022 during a virtual celebration event for all the students who applied to the competition. The winning teams will receive $1,500 to build their payloads and be awarded an assigned spot on a NASA-sponsored commercial suborbital flight.

Flight Opportunities seeks to continually expand options for flight testing through access to new vehicle capabilities and test regimes. In FY 2021, the program aided development of new commercial flight capabilities for technology demonstrations, including high-performance testing for spacecraft navigation and landing systems, extended lunar gravity environments, small launch vehicle first stage re-entry and recovery, and hypersonic re-entry test conditions.

Flight tests conducted in FY 2021 helped advance a variety of technologies that support NASA objectives. The impacts of a few of these tests are highlighted below.

- Flight Opportunities enabled testing of three technologies that are advancing in-space manufacturing of ZBLAN fibers, which can be developed in space with far fewer defects as compared to Earth-based manufacturing. Earth-based applications for ZBLAN include fiber optics, lenses, sensors, and optical devices with potential uses for telecommunications and laser technologies. Parabolic flight tests enabled researchers to advance these innovations ahead of demonstrations on the International Space Station (ISS).
- Flight Opportunities supported testing of a new nephelometer called NephEx – a sensor designed to provide information about a cloud's water content, as well as a cloud’s impact on a planet’s atmosphere or thermal and radiation environments. It could also supplement common techniques for cloud and climate monitoring, such as remote sensing via satellite. The flight test provided an important step in maturing the technology and assessing its capabilities to measure the size, concentration, and distribution of cloud particles – data critical to understanding the impact of clouds on a planet’s climate.
- On July 11, 2021, Virgin Galactic completed its first fully crewed spaceflight. Also aboard was a Flight Opportunities-supported technology: a space plants experiment operated by a crew member on behalf of researchers from the University of Florida in Gainesville. Three plant-filled tubes were activated to release a preservative at critical stages during the flight. The data collected is helping the

researchers assess the state of the plants at the cellular level at each stage of gravity, as well as better understand research opportunities for human-tended payloads. Flight Opportunities is also collaborating with the NASA Commercial Crew Program as they explore potential future use of commercial suborbital vehicles by NASA personnel.

- Also, in FY 2021, several technologies matured through Flight Opportunities transitioned to additional testing. Four Flight Opportunities-supported experiments were aboard Northrop Grumman's NG-16 Cygnus spacecraft, which arrived at the ISS on August 12, 2021. These included a Ring-Sheared Drop Experiment from NASA's Marshall Space Flight Center and Rensselaer Polytechnic Institute. This experiment aims to help researchers understand the formation of potentially destructive protein clusters and their role in neurodegenerative diseases. Also on board was a 3D Printing with Regolith experiment from Redwire Space. This work is helping to advance practices for in-situ resource utilization for additive manufacturing of parts, tools, and structures on the lunar surface.

While largely driven by the flight cadence of commercial flight providers, the Flight Opportunities program typically supports 15 or more suborbital flights each year. The program supported 32 flights in FY 2021 with more than 20 currently planned for FY 2022. Between the program's inception in 2011 and the end of FY 2021, Flight Opportunities has supported 230 successful fights and enabled 778 tests of payloads with the participation of 12 active commercial providers.

OTHER TECH DEMO

Fission Surface Power (FSP)

This project, as part of the Space Nuclear Technologies portfolio, is developing a small, lightweight fission power system that will enable long-duration lunar surface operations and is extensible for use on Mars. The goal is to demonstrate an integrated fission power system on the lunar surface to verify the engineering function, power performance, and operational reliability of the capability. Following a successful demonstration, this power technology will form a key capability for long-duration human surface missions on the Moon and eventually Mars. The technology will enable mission operations in harsh environments, such as permanently shadowed craters, and satisfy mission needs for continuous solar-independent power operations. This work is being conducted in collaboration with DOE.

In FY 2022, NASA released an industry solicitation for preliminary designs of and integrated fission power system, which will result in one-year performance contracts by the end of the fiscal year. NASA also initiated technology maturation efforts for the power conversion system and, in collaboration with the DOE, technology maturation for high-risk design elements. In FY 2023, NASA will use the information from the Phase I design study to formulate a follow-on effort and solicitation of industry proposal for the final design of the fission surface power systems.

Nuclear Propulsion

This effort, as part of the Space Nuclear Technologies portfolio, is advancing high-risk technologies for mass efficient space propulsion systems. The FY 2023 Budget for nuclear propulsion will enable NASA to complete the preliminary design phase for nuclear thermal propulsion fission reactors with industry. STMD also plans to evaluate propulsion thrusters for nuclear electric propulsion. NASA is collaborating with the Defense Advanced Research Projects Agency's (DARPA) Demonstration Rocket for Agile

Cislunar Operations (DRACO) using non-reimbursable engagement with industry participants where technology investments have common interest to both organizations. In FY 2021, NASA awarded three industry contracts to design an engineering scale fission reactor capable of generating propellant flow conditions compatible with the high-performance potential for nuclear propulsion. NASA also continued design efforts for engine turbine machinery and integrated system hardware, and advanced the technology maturity of reactor fuels and materials in concert with the Department of Energy (DOE) as risk reduction for a fission reactor. In FY 2022, NASA provided collaborative support to the DARPA DRACO flight demonstrator project with subject matter expertise, fuel testing, and turbine machinery design. These results are discussed further below.

Cryogenic Fluid Management (CFM)

Cryogenic fluid management is an enabling technology that holds the potential to support a human presence on a planetary surface as well as long-duration spaceflight by preserving chemical propellants. Improved cryogenic fluid management helps enable in-space transportation systems, such as human lander systems, and lunar and, eventually, Mars surface operations, including in-situ resource utilization. Missions that involve durations ranging from months to multiple years are far beyond the current state-of-the-art capabilities for in-space cryogenic fluid management.

As part of the 2020 Tipping Point solicitation, NASA requested proposals that would develop cryogenic fluid management tipping point technologies and integrated system capabilities for demonstration in relevant environments including in space (such as free flyers), the ISS, Lunar Gateway, and lunar payloads. The solicitation requested proposals to advance technologies in the areas of passive thermal control, tank pressure control, active cooling, and tank-to-tank propellant transfer. NASA selected four companies to issue milestone-based firm-fixed price contracts lasting up to five years to demonstrate these cryogenic fluid technologies. The four Tipping Point contracts were awarded between April and September 2021 and are expected to launch between FY 2023 and FY 2025.

Additionally, as part of the CFM portfolio, NASA has contracts to advance cryocoolers, a technology critical to long duration storage of cryogens, as well as a variety of in-house work related to the storage, transfer, and mass gauging of cryogenic fluids.

Low-Earth Orbit Flight Test of Inflatable Decelerator (LOFTID)

NASA, led by Langley Research Center in partnership with United Launch Alliance, will conduct a flight test of an inflatable aerodynamic decelerator technology to demonstrate its performance in environments relevant to several mission infusion opportunities. The Low-Earth Orbit Flight Test of Inflatable Decelerator (LOFTID) reentry vehicle (RV) will be flown as a secondary payload on an Atlas V launch vehicle. After the primary payload is delivered to the desired Earth orbit, the Atlas V Centaur upper stage will de-orbit the LOFTID RV. Prior to atmospheric entry, the RV will inflate the aeroshell, and then the Centaur will orient, spin-up, and release the RV for its spin-stabilized ballistic reentry. The flight will demonstrate the high-mass entry, descent, and landing technology at a scale (6-meter) and atmospheric conditions similar to landing large payloads on Mars as well as return from Earth orbit. This capability could also enable applications such as launch vehicle flight hardware recovery and reuse and return of products manufactured in space for terrestrial use. Conducting this effort with an industry cost-sharing partnership allows NASA to significantly reduce the overall cost of developing this technology while enabling a potential commercial user to gain insight into utilizing this technology for future booster recovery.

Mars Oxygen In-Situ Resource Utilization (ISRU) Experiment (MOXIE)

The Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE), led by the Jet Propulsion Laboratory (JPL), is designed for in-situ resource utilization technologies to enable propellant and consumable oxygen production from the Martian atmosphere for future exploration missions. Specifically, MOXIE produces oxygen from a Mars atmosphere in a variety of conditions, demonstrates the feasibility of ISRU on Mars, validates analytical models for scaling up of future ISRU systems, and provides valuable knowledge needed for future mission development. MOXIE is successfully operating as part of SMD's Mars 2020 mission.

On-Orbit Servicing and Manufacturing Demonstration-2 (OSAM-2/Archinaut)

In partnership with the commercial space industry, NASA is developing and will demonstrate technologies required to manufacture, assemble, and aggregate large and/or complex systems in space utilizing robotic and additive manufacturing technology.

Archinaut (Redwire) was awarded in July 2019 to develop a flight demonstration payload of their Phase I ground demonstration technology. Once deployed and positioned in orbit, a small spacecraft will 3D-print two beams. The first beam will extend nearly 33-feet from one side of the spacecraft while deploying a solar array surrogate. The second beam will extend nearly 20-feet from the opposite side of the spacecraft. This disruptive capability could transform the traditional spacecraft-manufacturing model by enabling in-space creation of large spacecraft systems. No longer will developing, building, and qualifying a spacecraft focus so heavily on an integrated system that must survive launch loads and environments. Archinaut could also greatly reduce cost while increasing capabilities for both NASA and commercial space applications.

Deep Space Optical Communication (DSOC)

Deep Space Optical Communication technologies are considered essential for future human missions to Mars and have a wide range of applications for planetary science missions including those to Mars and the Jovian systems. The Deep Space Optical Communications project, led by JPL, will develop key technologies for the demonstration of a deep space optical flight transceiver and ground receiver that will provide greater than 10 times the data rate of a state-of-the-art deep space radio frequency system (Ka-band). This capability will enable advanced instruments, live high-definition video, and telepresence that allow for deep space human exploration of the solar system.

NASA successfully completed and reduced significant risks on technologies including a low-mass spacecraft disturbance isolation assembly, a flight qualified photon counting detector array, a high-efficiency flight laser amplifier, and a high-efficiency photon counting detector array for the ground-based receiver. Combined, these components and subsystems make up the Deep Space Optical Communication system, which will demonstrate the high-bandwidth flight laser optical communication terminal on the SMD's Psyche mission.

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

Deep Space Atomic Clock (DSAC)

The Deep Space Atomic Clock project was launched via rideshare on a SpaceX Falcon Heavy (STP-2) in June 2019 and completed operations in August 2021. Led by JPL, DSAC had the objective to validate a miniaturized, mercury-ion atomic clock that is 50 times more stable than today's state-of-the-art space clocks used for spacecraft navigation systems. Deep Space Atomic Clock demonstrated ultra-precision timing in space and its benefits for one-way radio-based navigation. By successfully completing all of its requirements and objectives, DSAC enables freeing up precious deep space communications bandwidth to perform greater scientific data return. The enhanced navigation and increased communications bandwidth permitted by the new clock will dramatically improve the exploration mission's capability for on-board navigation, which is required for robust, safe human exploration beyond the Earth. Precision timing and navigation provided by the new clock will also have the potential to improve the Nation's next generation GPS system. The demonstration was funded in partnership with SCaN.

Laser Communications Relay Demonstration (LCRD)

The goal of the Laser Communications Relay Demonstration project is to prove the utility of bi-directional optical communications relay services between geosynchronous orbit and Earth. The project supports the advanced communications, navigation, and avionics exploration key focus areas. This effort will prove optical communications technology in an operational setting, providing data rates up to 100 times faster than today's radio frequency-based communication systems. The demonstration will measure and characterize the system performance over a variety of conditions, develop operational procedures, assess applicability for future missions, and provide an on-orbit capability for test and demonstration of standards for optical relay communications. This capability, if successfully demonstrated, could be infused into NASA missions, other Federal agencies, and U.S. satellite manufacturers and operators given the rising demand for bandwidth.

LCRD launched in December 2021 as a hosted payload with the U.S. Space Force Space Test Program 3 mission (STP-3). LCRD will conduct a minimum two-year flight demonstration to advance optical communications technology. Upon a successful flight demonstration, NASA will provide other users with access to the integrated system to test these new capabilities. Beyond LCRD commissioning, the Space Communications and Navigation (SCaN) Program will operate and maintain the LCRD payload utilizing the LCRD Mission Operations Center (LMOC). SCaN will support the LCRD mission demonstrations through the two-year prime demonstration operations period.

Recent and Planned Achievements

- Nuclear propulsion results in FY 2022 have advanced fuel element design and fabrication capabilities and provided manufacturing capabilities for high-temperature fuels forms and reactor moderator materials.
- In FY 2021, through industry collaboration arrangements, NASA awarded contracts to Eta Space, Lockheed Martin, SpaceX, and United Launch Alliance to develop and test technologies that enable long-term cryogenic fluid storage and management. These cryogenic fluid management technologies support a sustainable presence on the Moon, crewed missions to Mars, and enhanced in-space transportation capabilities for commercial and Government needs. Eta Space held its Mission Concept Review in December 2021. Lockheed Martin held its Integrated System Review (ISR-A)/Technology

Maturation Review (TMR-1) in December 2021. SpaceX held its Test Definition Review in November 2021. United Launch Alliance held its contract kick off in October 2021.

- TRN successfully operated on SMD's Mars 2020 mission in February 2021, landing the Perseverance rover within 6 seconds and within an accuracy of five meters.
- LOFTID completed a successful Critical Design Review/System Integration Review (CDR/SIR) in October 2020 and a successful KDP-D review in December 2020. The project is completing fabrication of flight hardware and Assembly, Integration and Test (AI&T) activities across all subsystems, leading to flight hardware readiness for Complete System Test (CST) in FY 2022. NASA and United Launch Alliance finalized plans to fly LOFTID as a rideshare with the Joint Polar Satellite System-2 (JPSS-2) spacecraft on the Atlas V. Project delivery to the launch site is currently planned for June 2022 and the current target launch date is September 2022.
- The MOXIE instrument was delivered to the Mars surface in February 2021. On April 20, 2021, MOXIE converted carbon dioxide into oxygen and the team has conducted eight different oxygen generating experiments to date. Analysis models are on-going to target the next set of test conditions.
- NASA released a solicitation for industry design efforts of a low-enriched uranium fuel power system. Industry proposals were submitted to NASA in March 2022 for evaluation and selection. Contract awards are planned by the end of FY 2022. NASA also modified the government reference design of a fission power system that has increased power levels from 10 kilowatt-electric to 40 kilowatt-electric and included a provisional assessment of design requirements for lunar surface mobility. In FY 2023, NASA will use the information from the Phase I design study to formulate a follow-on effort and solicitation of industry proposal for the final design of the fission surface power systems.
- On-Orbit Servicing and Manufacturing Demonstration-2 (Archinaut) was approved to enter Phase C (Final Design and Fabrication) at a STMD Program Management Council meeting in October 2020. In addition, the Extended Structure Additive Manufacturing Machine (ESAMM) Engineering Development Unit Vertical Print Test completed a 7-meter beam under expected flight loads in November 2020. The CDR was completed in December 2021 and launch is currently planned for no earlier than April 2023.
- The Deep Space Optical Communications flight unit was delivered on-time to the SMD Psyche mission on June 14, 2021. The flight accommodated Optical Platform Assembly is integrated onto Psyche and successfully passed functional tests. Launch is planned for late FY 2022.
- The Deep Space Atomic Clock successfully completed a second year of operation in orbit and released the DSAC Technology Advancement Report (DTAR) describing the DSAC technology, development, and experiences learned during the completed mission.
- LCRD launched on STPSat-6 for the U.S. Space Force STP-3 mission on December 7, 2021 and was powered up on January 12, 2022. LCRD made first connection with Optical Ground Station-2 located in Hawaii on January 19, 2022.

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

Acquisition Strategy

These critical technology projects are defined as part of the strategic framework and capabilities, and through requirements determined by the Federated Team, and through STMD's Strategic Technology Architecture Roundtable process. In addition, Space Technology embraces competition and external partnerships, as such some of the technologies are selected through annual Tipping Point, Announcement of Collaboration Opportunity, and other NASA solicitations.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
OSAM-2 (Archinaut)	Redwire	Jacksonville, FL

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Independent Review Team (IRT)	NASA	Sep 2020	DSOC Ground Critical Design Review	Passed	Operations Readiness Review of DSOC ground terminal May 2022
IRT	NASA	Oct 2020	LOFTID Critical Design Review	Passed	Operations Readiness Review Sep 2022
Independent Review Board (IRB)	NASA	Dec 2021	OSAM-2 Critical Design Review	Passed	System Integration Review Nov 2022

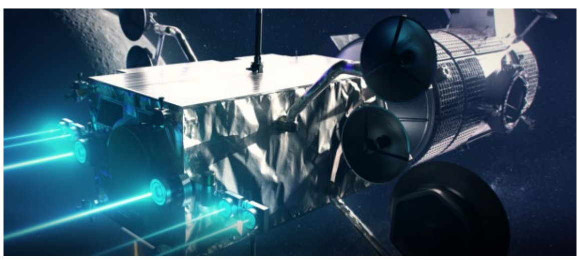
SBIR AND STTR

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**227.0**	**287.0**	**285.0**	**290.7**	**296.5**	**302.4**	**308.5**
Change from FY 2022 Budget Request			**-2.0**				
Percent change from FY 2022 Budget Request			**-0.7%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



Gateway is part of the Artemis program which will serve as a temporary habitat, laboratory, and staging area for missions to the lunar surface and destinations beyond the Moon.

Deployable Space Systems (DSS), an SBIR recipient, is providing the Roll Out Solar Array (ROSA) technology to supply power. ROSA is unique for its ability to roll up, allowing for huge solar arrays to be packaged for launch very compactly.

Busek, a woman-owned small business and SBIR recipient, will provide hall thrusters with high-efficiency propulsive capability that will convert the solar energy harnessed by ROSA into thrust. Solar electric propulsion missions can be conducted with a small fraction of propellant when compared to traditional chemical thruster systems.

NASA's Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs leverage the Nation's innovative small business community to fund research and development in support of NASA's mission in space technology, human exploration, science, and aeronautics. This program will also support NASA's Artemis Program objectives by identifying and accelerating relevant technologies drawn from the SBIR and STTR portfolios through Post Phase II awards. Post Phase II awards may involve matching funding from investors and further encourage the advancement of innovations and commercialization of technologies developed through Phase I and Phase II. These programs provide the small business sector with an opportunity to develop technology for NASA and to commercialize that technology to spur economic growth. NASA's SBIR/STTR programs will expand efforts to increase participation by women, socially or economically disadvantaged businesses, historically black colleges and universities (HBCU), and minority serving institutions (MSI), while also emphasizing entrepreneurial engagement.

The Agency actively works to facilitate the transition of NASA-funded SBIR and STTR technologies into missions and projects as well as commercial applications. Research and technologies funded by SBIR and STTR contracts have made important contributions to the Agency's mission. Examples include:

- An electrochemical system that recovers hydrogen and helium for rocket engine tests;
- Novel lightweight insulation that protects fuel tanks from extreme temperatures;

SBIR AND STTR

- A 3-D Bioprinter that overcomes gravity by printing living tissues in space; and
- Cryocooler electronics which control mechanical cryocoolers that enable thermal imaging systems to capture data to improve our knowledge of water and possibly life in space.

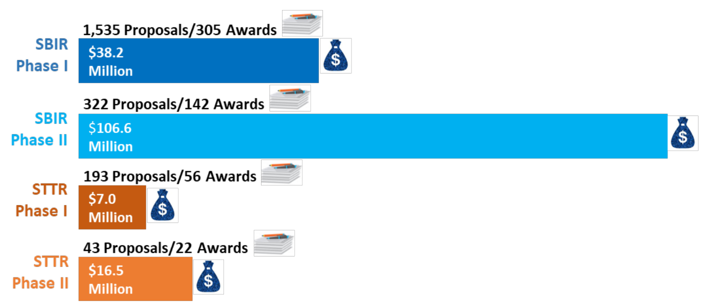
These investments seek to achieve the program's vision of empowering small businesses to deliver technological innovation that contributes to NASA's missions, provides societal benefit, and grows the U.S. economy.

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

ACHIEVEMENTS IN FY 2021

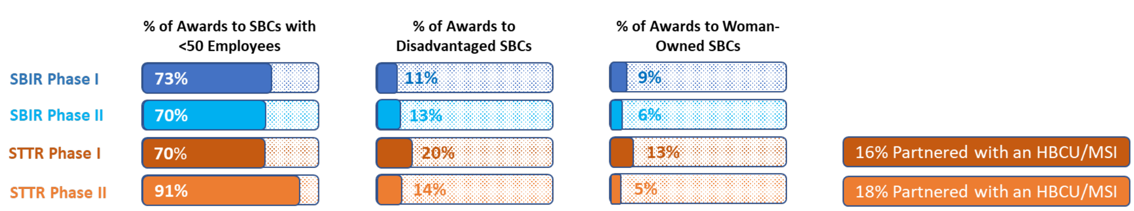
Phase I & II Awards



Post Phase II Awards

Program	# of Awards	SBIR/STTR Funding	Non SBIR/STTR Investor Funding
Phase II-Extended	35	$9.1 Million	$17.4 Million
CCRPP	6	$6.6 Million	$8.1 Million
Lunar-Focused Sequentials	5	$17.4 Million	N/A
Phase III	64	N/A	$24.6 Million

Phase I & II Demographics



- In November 2020, NASA released the FY 2021 SBIR/STTR annual solicitation two months early in order to give small businesses and research institutes an earlier opportunity for Phase I funding. From this solicitation, NASA awarded 361 new SBIR/STTR Phase I selections, valued at $45 million. In addition, NASA announced Phase II selections - 22 STTR awards from the FY 2019 solicitation with an approximate value of $16.5 million and 142 SBIR awards, with an approximate value of $106.6 million, from the 2020 solicitation.
- To increase technology transitions and commercialization, NASA offered Post Phase II award opportunities through vehicles such as the Phase II-Extended (II-E) program and the Civilian Commercialization Readiness Pilot Program (CCRPP) which both require firms to secure matching

investments from sources other than SBIR/STTR. In FY 2021, the maximum CCRPP award value increased to $3 million. The program made 35 II-E awards with an SBIR/STTR value of $9 million and 6 CCRPP awards with an SBIR/STTR award value of $6.6 million. The program also conducted its second round of the SBIR Phase II sequential vehicle focused on accelerating the development of existing Phase II technologies related to the return to the Moon and on to Mars. The program made 5 awards with a value of $17 million.

- In partnership with the National Science Foundation (NSF), NASA continued to make I-Corps training grant awards for Phase I awardees to encourage commercialization of technology and made 29 training grants valued at $384,000. The program also had its first selection of Post-Phase II participants with 2 Phase II-E awardees participating.
- NASA sought small business feedback to improve program responsiveness through a Section 280 customer experience clearance to conduct focused surveys and requests for information (RFIs). The program received customer experience survey input from 338 individuals and RFI feedback from 109 individuals. The program is incorporating the information gathered in ongoing service design and process improvement activities that will be completed in FY 2022. These activities will help the program modernize its business capabilities to reduce barriers to entry for firms, reduce the burden on the NASA technical community, increase the quality of proposals and selections, and improve the value proposition for firms.

WORK IN PROGRESS IN FY 2022

- STMD worked with the other NASA mission directorates, centers, and industry to identify subtopics, for the FY 2022 Solicitation, which was released in January 2022. While retaining an emphasis on subtopics with a strong relevance to Artemis and the Moon to Mars Campaign, the program also seeks to emphasize subtopics that support climate change and clean energy solutions.
- The SBIR program will identify and accelerate high priority technologies drawn from the SBIR portfolio through post Phase II awards, specifically the use of Phase II sequential awards to accelerate the use of SBIR technologies with a priority to support Artemis, and climate and clean energy objectives. The FY 2022 CCRPP opened November 12, 2021 and proposals were due January 18, 2022. The Phase II sequential call for white papers was released on January 14, 2022 and final selections will be made in the third quarter. The program continues to hold Phase II-E selection meetings roughly every other month with numerous opportunities for SBIR Phase II awardees to submit Phase II-E proposals every year.
- The program office is implementing techniques to further accelerate award timelines and improve the approachability of our program to entrepreneurial aerospace companies and underrepresented communities. The program is continuing several activities to encourage participation of underrepresented groups including a cooperative agreement with the MSI STEM Research & Development Consortium (MSRDC) and M-STTR Planning grants with NASA's Minority University Research and Education Project (MUREP). Additionally, SBIR has merged with the iTech program to enable the program to reach more entrepreneurial aerospace firms and pilot new vehicles that will resonate with their way of doing business. The program plans to hold an iTech event in Spring 2022, which would lead into a pilot commercial-focused solicitation in the summer with selections to be made in early FY 2023.

SBIR AND STTR

- In partnership with the National Science Foundation (NSF), NASA will continue to make I-Corps training grant awards for Phase I awardees to encourage commercialization of technology, expanded I-Corps participation to CCRPP, and Phase II-E awardees to assist the firms in meeting the commercialization goals of these programs.
- NASA will continue to pilot opportunities to accelerate NASA efforts in deep space exploration and those of the commercial aerospace sector. It will also expand efforts to support climate and clean energy technology development. Coordination has begun with NOAA SBIR to explore possible collaboration opportunities in an effort to reach entrepreneurs new to SBIR that are working to address climate change.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

- The program office will place additional emphasis on engaging a broad, diverse base of innovators through the program, especially in engagements with MSIs, including HBCUs, in addition to an increased emphasis on entrepreneurial engagement to encourage commercialization and economic impact.
- The program office will streamline award vehicles, improve market simulation through a commercial-focused pilot, and support iTech as a way to develop the pipeline of entrepreneurial firms.
- Award amounts for Phase I and II awards, will be increased for the first time in ten years to enable firms to meet NASA's demanding technology needs.
- NASA will implement new legislative authorities, as signed into law, such as direct to Phase II awards and expanded CCRPP.
- The SBIR and STTR program office will continue to work with all the NASA mission directorates, centers, and industry to identify subtopics including technologies to support human exploration to the Moon and eventually Mars as well as climate and clean energy challenges.
- In addition, this program will support NASA's Artemis Program and climate and clean energy objectives by identifying and accelerating relevant technologies drawn from the SBIR portfolios through Post Phase II awards.
- The SBIR and STTR program office will explore new opportunities to seek, select, advance technology R&D from small businesses, research institutions, and entrepreneurs where there is both NASA and commercial sector interest.

Program Elements

SBIR

The SBIR program was established by statute in 1982 and was most recently reauthorized in 2016 to increase research and development opportunities for small businesses. The program stimulates U.S. technological innovation, employs small businesses to meet Federal research and development needs, increases the ability for small businesses to commercialize innovations they derive from Federal research and development, and encourages and facilitates participation by socially disadvantaged businesses. The

SBIR AND STTR

SBIR program budget is based on a level of at least 3.2 percent of NASA's extramural research and development budget. The current maximum value for an SBIR Phase I contract is $150,000 for a period of performance of six months. For Phase II, NASA is planning to raise the maximum total value of an SBIR award from $750,000 to $1,000,000 over a 24-month period of performance for Phase II awards made from the FY 2022 solicitation which will be in FY 2023. NASA also supports several Post Phase II vehicles:

- Phase II-E contract options with incentives for cost sharing to extend the research and development efforts of the current Phase II contract.
- CCRPP contracts with incentives for cost sharing to extend the research and development efforts of the previous Phase II contract with strong customer pull for technology maturation, commercialization, and ultimately utilization versus incremental development.
- Phase II sequential contract options to help raise the Technology Readiness Level (TRL) value of technologies to the point that other investors will then advance the technology or to rapidly advance the TRL of a technology to enable NASA programs.
- I-Corps training grants to enable small businesses to commercialize their innovations through an Interagency Agreement with the NSF.

STTR

The STTR program was established by statute in 1992 and reauthorized in 2016 to award contracts to small businesses for cooperative research and development with a non-profit research institution, such as a university. NASA's STTR program facilitates transfer of technology developed by a research institution through the entrepreneurship of a small business, resulting in technology to meet NASA's core competency needs in support of its mission programs. Modeled after the SBIR program, STTR is funded based on 0.45 percent of the NASA extramural research and development budget. The maximum value for an STTR Phase I contract is $150,000 for a period of performance of 13 months. For Phase II, NASA is planning to raise the maximum total value of an STTR award from $750,000 to $1,000,000 over a 24-month period of performance for Phase II awards made from the FY 2022 solicitation which will be in FY 2024. Phase II E, CCRPP, Phase II sequential contract options, and I-Corps are also available to STTR participants.

SBIR AND STTR

Program Management & Commitments

Program Element	Provider
SBIR and STTR	Provider: Various Small Businesses and their research partners Lead Center: NASA HQ; Level 2: Ames Research Center (ARC) Performing Center(s): All centers play a project management and implementation role. Cost Share Partner(s): SBIR/STTR Phase II-E matches cost share funding with SBIR and STTR up to $375,000 of non-SBIR and non-STTR investment(s) from a NASA project, NASA contractor, other Government agency, or third-party commercial investor to extend an existing Phase II project to perform additional research. SBIR/STTR CCRPP matches cost share funding up to $2,500,000 of non-SBIR and non-STTR investment(s) from a NASA project, NASA contractor, other Government agency, or third-party commercial investor to continue a former Phase II project to perform additional research for strong customer pull for the technology maturation, commercialization, and ultimately utilization versus incremental development.

Acquisition Strategy

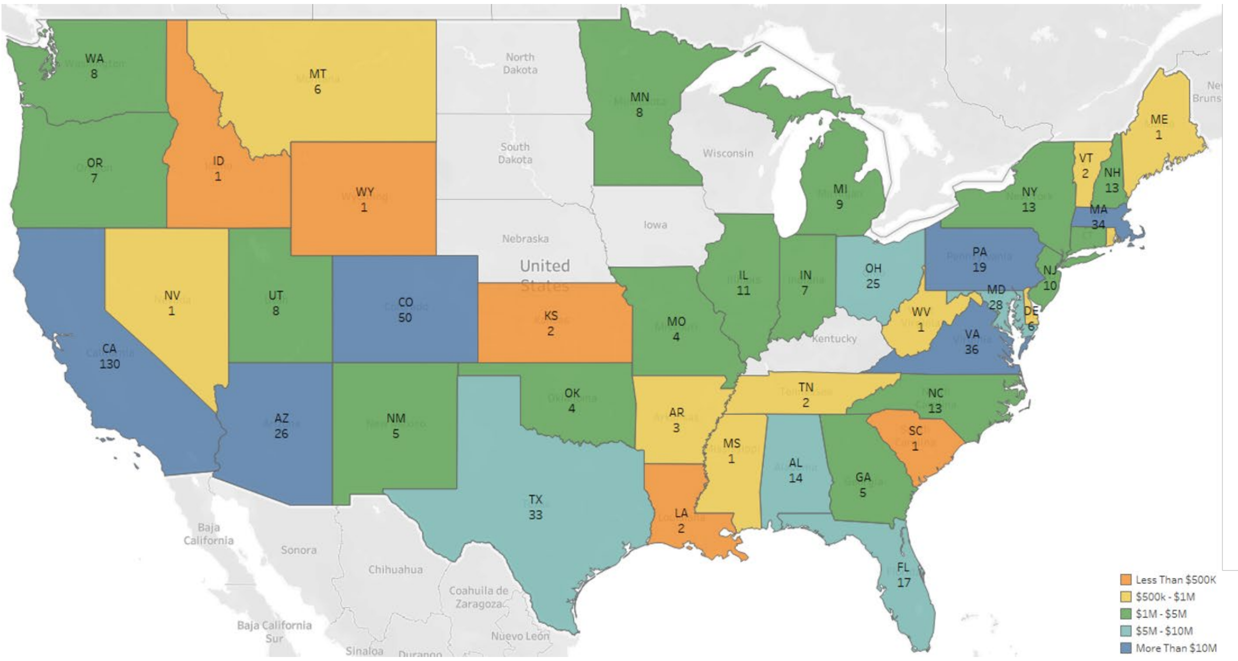
NASA issues annual SBIR and STTR program solicitations, setting forth a substantial number of topic areas open to qualified small businesses. There are three phases for SBIR and STTR funding awards. Phase I awards give small businesses the opportunity to establish the scientific, technical, and commercial merit of the proposed innovation in alignment with NASA interests. The most promising Phase I projects are selected for Phase II awards through a competitive selection process based on scientific and technical merit, expected value to NASA, and commercialization potential. Phase II awards focus on the development, demonstration, and delivery of the proposed innovation. Phase II-E and the CCRPP support advancement of innovations developed under Phase II. Phase III supports the commercialization of innovative technologies, products, and services that result from a Phase I or Phase II contract. Commercialization includes further development of technologies and getting feedback to discover infusion opportunities into NASA programs, other Government agencies, or the private sector. Phase III contracts receive funding from sources other than the SBIR and STTR programs and may be awarded without further competition.

SBIR and STTR program management works collaboratively with NASA center Chief Technologists (for STTR) and the mission directorates (for SBIR) during the SBIR and STTR acquisition process. This collaboration, from topic development through proposal review and ranking, supports final selection of proposals of high value to NASA. Mission directorates and center program personnel interact with SBIR and STTR award winners to maximize alignment and implementation of the SBIR and STTR products with NASA's future missions and systems.

SBIR AND STTR

Award Distribution

The map below represents the FY 2021 SBIR and STTR investments through Phase I, Phase II, Phase II-E, Sequential, and CCRPP awards.



SCIENCE

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Earth Science	1,996.5	2,250.0	**2,411.5**	2,460.3	2,589.0	2,722.3	2,782.0
Planetary Science	2,693.2	3,200.0	**3,160.2**	3,186.1	3,197.4	3,176.4	3,299.0
Astrophysics	1,770.9	1,575.2	**1,556.0**	1,597.0	1,578.5	1,620.5	1,625.6
Heliophysics	751.0	797.2	**760.2**	802.6	842.0	851.9	831.9
Biological and Physical Sciences	79.1	109.1	**100.4**	102.1	104.1	106.2	108.4
Total Budget	**7,290.7**	**7,931.4**	**7,988.3**	**8,148.1**	**8,311.1**	**8,477.3**	**8,646.8**

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

SCIENCE

Planetary Science

Astrophysics

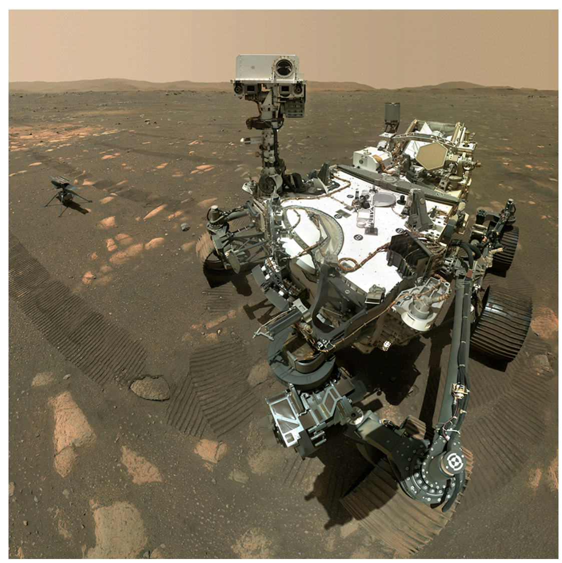
SCIENCE

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Earth Science	1,996.5	2,250.0	**2,411.5**	2,460.3	2,589.0	2,722.3	2,782.0
Planetary Science	2,693.2	3,200.0	**3,160.2**	3,186.1	3,197.4	3,176.4	3,299.0
Astrophysics	1,770.9	1,575.2	**1,556.0**	1,597.0	1,578.5	1,620.5	1,625.6
Heliophysics	751.0	797.2	**760.2**	802.6	842.0	851.9	831.9
Biological and Physical Sciences	79.1	109.1	**100.4**	102.1	104.1	106.2	108.4
Total Budget	**7,290.7**	**7,931.4**	**7,988.3**	**8,148.1**	**8,311.1**	**8,477.3**	**8,646.8**
Change from FY 2022 Budget Request			**56.9**				
Percent change from FY 2022 Budget Request			**0.7%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



NASA's Perseverance Mars rover took a selfie with the Ingenuity helicopter, seen here about 13 feet (3.9 meters) from the rover. The rover landed successfully on Mars on February 18, 2021 and has begun its search for signs of ancient microbial life.

Since NASA's inception, scientific discovery about our Earth, the Sun, the solar system, and the universe beyond has been an enduring purpose of the Agency. NASA's Science Mission Directorate (SMD) conducts scientific exploration enabled by observatories that view Earth from space, observe and visit other bodies in the solar system, and gaze out into the galaxy and beyond. NASA's scientific exploration will also inform human exploration of the Moon, Mars, and the solar system, providing valuable scientific data for such human missions. The goal of NASA's science programs is to expand human knowledge through new scientific discoveries, focused on three objectives:

- Understand the Earth system and its climate;
- Understand the Sun, solar system, and universe; and
- Ensure NASA's science data are accessible to all and produce practical benefits to society.

NASA science programs address fundamental research about the universe and humanity's place in it. How did the universe begin and evolve? How did the solar system originate? How and why is the Earth changing on all timescales? This fundamental research covers all areas of science and the intersections thereof when addressing the question, "Are we alone?" NASA's science programs also help protect and improve life on Earth through fundamental research that enables innovative and practical applications for decision-makers, including disaster response, natural resource management, and planetary defense. NASA also focuses on improving its operations and launching its science missions on schedule and on budget. NASA's discoveries continue to rewrite textbooks, inspire learners of all ages, and demonstrate U.S. leadership worldwide.

NASA uses the recommendations of the National Academies' decadal surveys as important inputs in planning and prioritizing the future of its science programs. For almost 60 years, decadal surveys have proven vital in establishing a broad consensus within the national science community on the state of science, the highest priority science questions we can address, and actions we can take to answer those questions. NASA uses these recommendations to prioritize future flight missions (including space observatories and probes) as well as technology development and proposals for theoretical and suborbital supporting research. In 2021, NASA received a new decadal survey for Astrophysics. NASA expects to receive decadal surveys for Planetary Science (2022), Biological and Physical Sciences (2023), and Heliophysics (2024) in the coming years. In determining the content of the Science portfolio, NASA also considers national priorities and policies, budgets, existing technological capabilities, partnership opportunities, and other programmatic factors.

EXPLANATION OF MAJOR CHANGES IN FY 2023

The Budget provides $8.0 billion for Science, the highest ever including funds for the James Webb Space Telescope, the Mars Sample Return mission, and implementation of the Earth System Observatory. Within Earth Science, in addition to ramping up development of missions that will comprise the Earth System Observatory, the Budget enables NASA to pursue innovative ways to ensure sustained climate observations provide ongoing records of the changing climate and Earth system. Additional funds are requested to support a coordinated Agency wildfire initiative to leverage NASA expertise and assets to address scientific and technological barriers in wildfire risk management. Additionally, as part of a renewed emphasis on providing actionable data and information to a broad range of users, NASA is planning an Earth Information Center with an initial focus on prototyping capabilities for a greenhouse gas monitoring and information system that will integrate data from a variety of sources with a goal of making data more accessible and usable to Federal, State, and local governments, researchers, the public, and other users. These efforts will be implemented in coordination with other agencies and partners.

Within Planetary Science, funds are requested to support the newest Discovery selections, two missions to investigate Venus: DAVINCI (Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging) and VERITAS (Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy). The budget request includes additional funding for Europa Clipper due to significant COVID impacts and to accommodate increased estimates for operations. The budget request also proposes a two-year delay of the NEO Surveyor mission and discontinues NASA funding for the Mars Ice Mapper international collaboration to support higher priority missions within Planetary Science, including additional funds for Mars Sample Return in FY 2023 to continue formulation of the dual-lander architecture (see MSR program section for more details).

Within Astrophysics, an initial response to the 2020 Astrophysics Decadal Survey includes targeted funding to support recommended precursor science and technology investigations, as well as diversity and inclusion initiatives within Astrophysics research. The James Webb Space Telescope is no longer shown as a separate Theme, but as an operating mission within the Cosmic Origins Program. Funding for Webb competitive science awards (part of the operating budget) is now shown separately in the Webb Science line and has been augmented to assure robust selection rates throughout prime mission operations. The Budget proposes to close out the SOFIA mission in FY 2023. The decadal survey found that SOFIA's low science productivity cannot justify its high operating costs. The National Academies have recommended that NASA terminate operations by 2023.

Within Heliophysics, a new Space Weather Program is proposed. The program will play a vital role in the national space weather enterprise by providing unique and impactful observations and data streams for theory, modeling, and data-driven analysis. The program will combine competed research and technology with Space Weather flight missions. The Living With a Star Program includes a new Orbital Debris & Space Situational Awareness (OD-SSA) initiative. This addresses a knowledge gap of near-Earth space by focusing on orbital objects of both natural and anthropogenic sources that cannot be directly characterized by ground measurements.

Within Biological and Physical Sciences, compared to the plan proposed in the FY 2022 request, NASA will delay expanding Space Biology investigations and developing a facility to conduct Soft Matter research in low-Earth orbit. NASA will reassess its BPS portfolio once the results of the 2023 Decadal Survey are available.

ACHIEVEMENTS IN FY 2021

SCIENCE RESULTS

NASA investments continue to generate productive science and meaningful results. In Planetary Science, six months after the Mars Rover 2020 landing, the Perseverance rover successfully collected its first set of rock samples. Analysis of observation data for the sample site of the level of alteration in the analyzed rocks suggests that groundwater was present for a long time in Jezero Crater - an indication that a potentially habitable environment was sustained for a substantial period. Perseverance’s first science campaign has explored Jezero’s deepest, and most ancient layers of exposed bedrock and other intriguing features through a series of geologic units. Of the initial two units to be explored, the first unit is called “Crater Floor Fractured Rough” and is material that has filled the crater floor of Jezero crater. The adjacent unit, named “Séítah” (meaning “amidst the sand” in the Navajo language), includes Mars bedrock but is also home to ridges, layered rocks, and sand dunes. The goal of this first campaign is to determine which locations in these units reveal Jezero Crater’s earliest environment and geologic history, and to then collect rock samples at those locations.

Several published papers last year studied sea ice properties, its thickness, and changes cited ICESat-2. A research team demonstrated, for the first time, that ICESat-2 can detect summer melt features on sea ice from a spaceborne altimeter system. They showed that ICESat-2 provides precise measurements of sea ice surface roughness, pressure ridge height, and sea ice floe size distribution, resolving features as narrow as 7 meters and achieving a vertical height precision of 0.01 meter. A study used ICESat-2 photon data and coincident high-resolution satellite imagery from WorldView-2 and Sentinel-2 over different sea ice topographies to locate individual melt ponds on Arctic sea ice during the summer months. Sea ice melt ponds reduce both the reflective and insulative properties of sea ice; determining their locations on sea ice is a critical observation for accurately calculating sea ice height and sea ice freeboard (i.e., the thickness of sea ice protruding above the water level).

The Parker Solar Probe mission recently shed new light on the structure and behavior of the inner Solar System dust environment. Scientists using data from Parker Solar Probe have assembled a comprehensive picture of the structure and behavior of the large cloud of space dust, a zodiacal cloud, that swirls through the innermost solar system - and the new insight offers clues to similar clouds around stars across the universe. Every stellar system has a zodiacal cloud, a dusty cloud of grains shed from passing comets and asteroids. Researchers saw impacts that were consistent with the two primary dust populations in the zodiacal cloud. The first population are grains being slowly pulled in toward the Sun over thousands to millions of years; then, as the swirling cloud gets denser, the larger grains collide and create fragments – called beta-meteoroids – that are pushed out of the solar system in all directions by pressure from sunlight. This concept addresses a fundamental process that would be occurring not only at every meteoroid stream in our solar system, but with every meteoroid stream to varying degrees in every dust cloud in the universe.

In FY 2021, NASA researchers conducted a series of plant biology experiments on the International Space station to investigate how plants respond and adapt to the space environment in order to enable space crop production. Researchers completed the Advanced Planet Experiments and studied the effects of environmental conditions on plant growth to identify novel genetic engineering strategies for improving plant adaptation in space and on Earth. The Planet Habit experiment investigated the effects of spaceflight on radishes. This knowledge will be essential for the transition from Earth-bound cultivation of plants to growth conditions in space, and to enable the development of nutritionally valuable food crops that can be reliably grown in a space environment. Biological and Physical Science is also collaborating with the Human Research Program to study both the psychological benefits to humans of having plants in space, as well as ways to improve the taste of space-grown food on the space station.

NASA highlights these and many other scientific results in the pages that follow.

COST AND SCHEDULE PERFORMANCE

This Budget reports recent cost increases and/or schedule delays above Agency commitments on the Webb, MAIA, GeoCarb, and Europa Clipper missions. Each of these missions has experienced significant disruptions due to the COVID-19 pandemic as contributing factors to the increases and/or delays. Since 2011, when NASA implemented a requirement for most missions entering development to budget at the 70 percent joint cost and schedule confidence level, NASA has launched 23 Science missions subject to this requirement, with a total net budget overrun of 3.7 percent (including Webb). Thirteen of these 23 missions launched on or ahead of NASA's original commitment date.

In the last 12 months, NASA successfully completed or launched five missions: Landsat 9, Lucy, IXPE, DART, and the James Webb Space Telescope. Landsat 9 launched in September 2021, two months earlier than planned and 27 percent under planned development costs. Lucy launched in October 2021, one month earlier than planned and nine percent under planned development costs. IXPE launched in December 2021, two months later than planned and one percent over planned development costs. Webb launched in December 2021, 10 months later than the most recent schedule commitment. Final development costs for Webb will not be available until the conclusion of on-orbit commissioning, currently planned for June 2022. Landsat 9, Lucy, DART, and IXPE are now conducting prime mission operations.

WORK IN PROGRESS IN FY 2022

NASA Science includes over 100 missions, most of which involve collaboration with international partners or other U.S. agencies. Work on over 45 missions in formulation and development continues, despite significant COVID-19 disruptions at NASA centers and contractor sites. In the first quarter of FY

2022, NASA launched the Lucy, IXPE, DART and Webb missions. NASA will also launch TROPICS, Psyche, and Janus during FY 2022. Operations of more than 60 other Science missions also continue, including the Mars Perseverance Rover and OSIRIS-REx, on its way back to Earth with samples of the asteroid Bennu. In late 2022, NASA expects the first deliveries of NASA science payloads to the lunar surface under the Commercial Lunar Payload Services (CLPS) initiative. CLPS is opening competition to United States commercial providers of space transportation services, with the strategic goal of supporting affordable commercial operations on and near the Moon.

In FY 2022, NASA will complete commissioning of the Webb spacecraft and instruments, including the complex process of mirror alignment, and will release the mission's first science images.

More than 4,000 competitively selected research awards will continue to scientists located at universities, independent research centers, NASA field centers, industry, and other Government agencies. NASA Science will continue the use of Dual-Anonymous Peer Review in competitive research solicitations to ensure that the review of proposals is performed in an equitable and fair manner. NASA Science will continue development of a "bridge partnerships" program. These three-way agreements between NASA centers, minority-serving institutions/students, and high-research intensity universities will aid minority-serving institutions in applying for and managing NASA research grants, as well as give students access to NASA scientists, engineers, and facilities. In FY 2022, NASA Science will continue to invest in the adoption of open-source science principles and infrastructure, as well as innovative tools for data storage and analysis (such as artificial intelligence and machine learning). These practices have the potential to dramatically accelerate scientific discovery and to expand access to scientific knowledge produced by NASA.

During FY 2022, NASA selected two new Heliophysics Medium Explorer (MIDEX) missions, MUSE and HelioSwarm, and will make initial selections (concept studies) for the next Astrophysics Medium Explorer mission. NASA will release the first Announcement of Opportunity within the new Earth Explorer Program to solicit proposals for new PI-led missions investigating one or more of the 2017 Decadal Survey Earth System Explorer Targeted Observables. NASA expects to receive the next Planetary Science Decadal Survey from the National Academies, which will guide Planetary Science mission planning for the decade spanning 2022-2032.

NASA continues to be actively engaged in the development and utilization of SmallSats/CubeSats as a part of a balanced program of discovery. NASA will use SmallSats/CubeSats to perform technology demonstrations, train and develop the future workforce, and enable unique science observations. In FY 2022, NASA will launch the Time-Resolved Observations of Precipitation Structure and Storm Intensity with a Constellation of SmallSats (TROPICS) mission, consisting of six CubeSats to make measurements over the tropical latitudes to observe the lifecycle of tropical cyclones. These CubeSats will be launched on a new class of commercial launch vehicles specifically designed for smaller, high risk-tolerant payloads. NASA Science will also launch the Janus mission, consisting of two SmallSats that will visit two binary asteroids to study the formation of small "rubble pile" asteroids. The mission will launch as a secondary payload (or "rideshare") with the Psyche spacecraft in August 2022 and arrive at the two binary asteroids in 2026. In FY 2022, development will continue on other SmallSat/CubeSat missions including Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS), Polarimeter to Unify the Corona and Heliosphere (PUNCH), Escape and Plasma Acceleration and Dynamics Explorers (ESCAPADE), Polar Radiant Energy in the Far-InfraRed Experiment (PREFIRE), and Sun Radio Interferometer Space Experiment (SunRISE).

SCIENCE

KEY ACHIEVEMENTS PLANNED FOR FY 2023

In FY 2023, NASA plans to launch SWOT, EMIT, TEMPO, PREFIRE, and AWE, as well as the X-ray Imaging and Spectroscopy Mission (XRISM) with JAXA. Mission selections are planned from the Earth Venture Instrument-6 Announcement of Opportunity (AO) and the Heliophysics Small Explorer (SMEX) AO (step 1). Within the Lunar Discovery & Exploration Program additional Commercial Lunar Payload Services deliveries will occur, delivering new lunar science payloads to the surface of the Moon.

In FY 2023, the Mars Sample Return mission will complete its preliminary design and NASA will conduct a mission confirmation review. NASA expects to receive the Biological and Physical Sciences Decadal Survey from the National Academies, which will guide BPS research investigation planning for the decade spanning 2023-2033.

Progress on the Earth System Observatory will continue, with four missions in the formulation phase addressing high priority climate science areas in Aerosols; Clouds, Convection, and Precipitation; Mass Change; and Surface Biology and Geology.

In FY 2023, the IMAP instrument teams and subsystems will build, test, and deliver to APL the final flight hardware, following their respective System Integration Reviews (SIRs). The project will then conduct a mission-level Systems Integration Review, and NASA will conduct a KDP-D review which authorizes the project to proceed to the phase of System Assembly, Integration & Test. MUSE and HelioSwarm will complete their Preliminary Design Reviews and progress towards confirmation.

For the Wildfires initiative, Earth Science will conduct outreach and site visits, organize, and host a series of stakeholder engagement workshops, and create partnerships to deliver substantial improvements in wildfire management, working closely with the wildfire community, the Aeronautics Research Mission Directorate and Space Technology Mission Directorate. NASA will enhance collection of GHG data from aircraft and instruments, and expand existing activities including the legacy Carbon Monitoring System, competed research, and support for GHG measurement networks.

Themes

EARTH SCIENCE

From the vantage point of space, NASA satellites can view and study our home planet and its dynamic system of diverse components: the oceans, atmosphere, continents, ice sheets, and life. The Nation’s scientific community can thereby observe and track global-scale changes, connecting causes to effects. Scientists can study regional changes in their global context, as well as observe the role that human civilization plays as a force of change. NASA’s Earth Science activities are an essential part of national and international efforts to understand change at all timescales and to use Earth observations and scientific understanding in service of society. Through its partnerships with other agencies that maintain forecasting and decision support systems, NASA helps to advance National capabilities to predict climate, weather, and natural hazards; manage resources; and inform the development of environmental policy. Additionally, NASA will collaborate with other agencies to enhance greenhouse gas monitoring and make greenhouse gas data more accessible to a broad range of users.

SCIENCE

In January 2018, the National Academies released the second Decadal Survey for Earth Science and Applications from Space, which provided recommendations for the next decade (2018 - 2027). The primary recommendations are underlined below, followed by current status:

- Complete the program of record, including maintaining the Venture Class program and completing missions currently in formulation and development. This budget supports this recommendation.
- Establish a "Continuity" strand as an addition to the existing Venture Class program to provide opportunities for the demonstration of low-cost sustained observations. This budget supports this recommendation within Venture Class missions. The first Earth Venture Continuity mission, Libera, was selected in February 2020 and will maintain the 40-year data record of the balance between the solar radiation entering Earth's atmosphere and the amount absorbed, reflected, and emitted.
- Implement cost-capped medium- and large-size missions/observing systems to address the five "Designated" observables (Aerosols; Clouds, Convection, and Precipitation; Mass Change; Surface Biology and Geology; Surface Deformation and Change). The budget supports this recommendation by continuing the development of the Earth System Observatory. Formulation activities are underway for missions to address the first four of these Designated observables. NASA-ISRO Synthetic Aperture Radar (NISAR) is the precursor to the Surface Deformation and Change mission.
- Establish a new competed "Explorer" flight line to provide opportunities for cost-capped medium-size Principal Investigator (PI)-led instruments and missions. This budget supports the Earth Explorer program, and the selection of mission concept studies for the first Earth System Explorer missions.
- Establish an "Incubator Program" to mature specific technologies for important – but presently immature – measurements. This budget continues to support this recommendation with the Decadal Incubation Project within the Earth Science Technology Program, which includes projects addressing all 20 observables highlighted in the Decadal Survey.

NASA seeks input from the Earth Science Advisory Committee to ensure that our proposed programs maximize scientific productivity within the general framework established by the National Academies.

In addition to addressing the recommendations described above, this budget supports translating Earth science into actionable data and information via investments in Applied Sciences, which will support applications and user engagement related to wildfires, environmental justice, energy, and agriculture. NASA will work jointly with EPA to develop a greenhouse gas monitoring and information system that will integrate data from a variety of sources with a goal of making data more accessible to Federal, State, and local governments, as well as other users. NASA will also pursue key climate continuity measurements and advance open science for all by leveraging cutting edge data science techniques.

PLANETARY SCIENCE

To answer questions about the solar system and the origins of life, NASA sends robotic space probes to the Moon, other planets and their moons, asteroids and comets, and the icy bodies beyond Neptune. In early FY 2021, the New Frontiers OSIRIS-REx spacecraft completed a successful Touch-And-Go (TAG) sample collection event on the asteroid Bennu's surface, over 200 million miles away from Earth, and is now headed back to Earth with those samples, scheduled for return in 2023. In February 2021, the Mars Rover 2020, also known as Perseverance, arrived on Mars and just two months later the Ingenuity helicopter successfully executed the first ever powered and controlled flight on another planet. Perseverance is addressing key questions about the potential for ancient life on Mars and is caching samples for the future Mars Sample Return mission which is currently in formulation. NASA is operating spacecraft at Mars, Jupiter, and the Moon, and launched two missions to asteroids in early FY 2022, Lucy to study the Trojan asteroids and DART on a planetary defense mission to hit and change the course of the moonlet of Near-Earth asteroid Didymos.

The primary recommendations of the National Academies' 2012 Decadal Survey for Planetary Science are underlined below, followed by current status:

- Continue Discovery Announcements of Opportunity (AOs), with a 24-month mission cadence and cost cap adjusted for inflation. The budget request supports the two new Discovery 2019 AO missions, VERITAS and DAVINCI, selected in June of 2021 for launch no earlier than 2028. The next planned Discovery AO will be released no earlier than 2025. NASA plans for upcoming AOs to continue with a cost cap of $500 million in FY 2019 constant dollars for Phases A through D, not including the cost of the launch vehicle or the value of any non-NASA contributions. This cost cap is equivalent to the $450 million in the previous AO from FY 2015, which led to the selection of the Lucy and Psyche missions.
- Continue New Frontiers with a $1 billion cost cap and select two new missions by 2022. This budget supports the recommended cost cap for the AO released in February 2017, which resulted in the 2019 selection of the Dragonfly mission to Saturn's moon Titan. The next New Frontiers AO will be released no earlier than 2023.
- Begin the two highest priority flagships: a Mars Astrobiology Explorer-Cacher and a Europa mission. This budget supports both the Mars Rover 2020 mission (launched July 30, 2020) that will address the highest priority Mars science objectives recommended by the Planetary Decadal Survey and the Europa Clipper mission. The budget includes $822 million in FY 2023 toward development (along with international partners) of the Mars Sample Return mission, launching as early as 2028.
- Continue missions in development and flight, subject to senior review. This budget supports all missions selected for development, all missions in prime operations, and all missions in extended operations.
- Increase research and analysis (R&A) spending by 5 percent above the FY 2011 budget level, and then 1.5 percent above inflation thereafter. This budget meets the recommendation.
- Increase Planetary Technology spending to six to eight percent of the total division budget, including completion of the advanced Stirling radioisotope generators. This budget supports technology spending equivalent to four percent of the division budget in FY 2023 and includes funding for dynamic radioisotope power system development.
- Achieve a balanced program through a mix of Discovery, New Frontiers, and flagship missions and an appropriate balance among the many potential targets in the solar system. This budget supports the competed, Principal Investigator (PI)-led programs (Discovery and New Frontiers) and two flagship missions (Mars Sample Return and Europa Clipper). It includes a Planetary Decadal Future funding line beginning in FY 2025 to begin formulation studies of a future flagship mission. Increased funding needs for Mars Sample Return, which now requires a second lander, is placing pressure on the rest of the Planetary Science portfolio and may impact the balance of the portfolio in future years.

NASA asks the Planetary Science Advisory Committee for input to ensure that our proposed programs maximize scientific productivity within the general framework established by the National Academies.

SCIENCE

ASTROPHYSICS

We stand on the threshold of new endeavors that will transform not only our understanding of the universe and the processes and physical paradigms that govern it, but also humanity's place in it. Progress in understanding pathways to habitable worlds, opening new windows on the dynamic universe, and unveiling the drivers of galaxy growth require the essential vantage point of space. Building on the revolutionary advances in our observations of exoplanets, we now seek to identify and characterize Earth-like extrasolar planets, with the ultimate goal of obtaining imaging and spectroscopy of potentially habitable worlds. We aim to exploit the new observational tools of gravitational waves and particles, along with temporal monitoring of the sky across the electromagnetic spectrum and wide-area surveys to probe the most energetic processes in the universe and also address the nature of dark matter, dark energy, and cosmological inflation. By linking observations and modeling of the stars, galaxies, and the gas and energetic processes that couple their formation, evolution, and destinies, we can revolutionize our understanding of the origins and evolution of galaxies, from the nature of the tenuous cosmic webs of gas that feed them, to the nature of how this gas condenses and drives the formation of stars.

The National Academies released the new decadal survey in 2021, "Pathways to Discovery in Astronomy and Astrophysics for the 2020s." It recommends a coordinated program of research, technology development, ground-based facilities, and space-based missions for implementation, as well as addressing inclusion, diversity, and training necessary to maintain the health of the astrophysics profession. The primary recommendations are underlined below, followed by current status:

- Foundations of the Profession: Addressing inclusion, diversity, training, and the profession. The budget continues investment in the SMD Bridge Program to strengthen partnerships with minority-serving institutions to broaden participation in NASA's science research programs and initiates an Astrophysics mission design summer school to help train new Principal Investigators. The Research Program includes further expansion of the ROSES Inclusion Plan Pilot with incorporation into selection decisions in 2023. Continuation of the NASA Hubble Fellowship Program will encourage development of scientific leaders who advance diversity and inclusive excellence, in accordance with the external NASA Hubble Fellowship Program Review.
- Research Foundation: Improvements to research and analysis and data centers. NASA will continue to release data on proposal success rates at all AAS Town Halls and Astrophysics Advisory Committee meetings. Increases in Research and Analysis, as recommended by the Decadal Survey, are included in the budget.
- Balancing the Operating Portfolio. The survey committee found that SOFIA's low science productivity cannot justify its high operating costs. Consistent with the recommendation, the budget supports an orderly closeout of SOFIA in FY 2023. The budget supports other operating missions and the Balloon Program.
- Technological Foundation: Improvements to technology development programs and the balloon program. The budget includes the Strategic Astrophysics Technology program, which matures technologies for identified future Great Observatories and identified future Probe missions. The budget supports the SPHEREx and COSI missions, as well as the next MIDEX and SMEX. The budget supports an external review of the balloon program.
- Time Domain Astrophysics and Multi-Messenger Program: Realize and sustain the suite of electromagnetic capabilities required to study transient and time-variable phenomena, and to follow-up multi-messenger events. NASA is developing actions to address the Time Domain Astrophysics

and Multi Messenger (TDAMM) recommendations of the 2020 Decadal Survey. The budget supports the operation and development of missions that address TDAMM priorities including Swift, Fermi, TESS, UltraSat, COSI, and Roman. In addition to flight missions, the budget supports multi-mission, interagency, and international coordination in the areas of data archives, data standards, transient alerts, and community research opportunities.

- Astrophysics Probe class missions. The budget supports the release of an Announcement of Opportunity for the first Astrophysics Probe no earlier than FY 2023 and the selection of two to three proposals for competitive Phase A mission concept studies.
- Great Observatories. NASA's priority is ensuring mission success for Webb and Roman. The budget includes enabling science and technology investments that are responsive to Decadal Survey science priorities for future Great Observatories.

NASA asks the Astrophysics Advisory Committee for input to ensure that our proposed programs maximize scientific productivity within the general framework established by the National Academies.

HELIOPHYSICS

The Sun, a typical small star midway through its life, governs our solar system. The Sun wields its influence through its gravity, radiation, solar wind, and magnetic fields, all of which interact with the Earth and its space environment. These processes are crucial for our understanding of the universe, and they relate directly to our ability to live in space as they produce space weather, which can affect human technological infrastructure and activities in space. Using a fleet of sensors on various spacecraft in Earth orbit and throughout the heliosphere, NASA seeks to understand the fundamental processes of how and why the Sun varies, how Earth and our solar system respond to the Sun, how the Sun and the solar system interact with the interstellar medium, and how human activities are affected by these processes. The science of heliophysics, including space weather, enables the predictions necessary to safeguard life and society on Earth and the outward journeys of human and robotic explorers.

The primary recommendations of the National Academies' 2013 Decadal Survey for Heliophysics are underlined below, followed by current status:

- Maintain and complete the current program. The Decadal Survey assumed launch of Van Allen Probes by 2012, Interface Region Imaging Spectrograph (IRIS) by 2013, Magnetospheric Multiscale (MMS) by 2014, Solar Orbiter Collaboration (SOC) by 2017, Parker Solar Probe by 2018, and continued current funding of the research program. Van Allen, IRIS, MMS, Parker Solar Probe, and the ESA-led Solar Orbiter Collaboration have all successfully launched. The Global Scale Observations of the Limb and Disk (GOLD), Ionospheric Connection Explorer (ICON) and the Space Environment Testbed missions have also successfully launched and are in primary operations or have achieved mission success criteria. Support for 20 operating missions and associated research has also continued.
- Implement the DRIVE (Diversify, Realize, Integrate, Venture, Educate) initiative, including the incorporation of smaller spacecraft and an increase in the competed research program from 10 percent to about 15 percent of the budget request. This budget supports competed research funding equivalent to approximately 14 percent of the division budget in FY 2023 and invests in the SMD-wide CubeSat/SmallSat initiative. DRIVE Science Centers (DSCs) address grand challenge goals that are both ambitious and focused enough to be achievable within the lifetime of the center - in other words, problems poised and ready for major advances. DRIVE has been fully implemented and is now

considered part of the Heliophysics Research and Analysis (R&A) program. NASA is preparing for selection of Phase 2 DRIVE Science Centers in FY 2022.

- Accelerate and expand the Heliophysics Explorer Program, resulting in an increase to the cadence of competed missions to one launch every two to three years. NASA launched IRIS in 2013, Global-Scale Observations of the Limb and Disk (GOLD) in 2018, and ICON in October 2019. The proposed out-year budgets, if realized, would enable launch of Atmospheric Waves Experiment (AWE) mission of opportunity in FY 2023, Polarimeter to Unify the Corona and Heliosphere (PUNCH) as early as FY 2025 and Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS) no earlier than 2024. The budget also supports the launch by 2027 of one of the recently selected MIDEX missions. NASA has maintained an Explorer mission cadence of every two to three years and plans additional launches approximately every two years thereafter with planned SMEX 2022 and MIDEX 2025 Announcements of Opportunity. The increased cadence of Explorers has contributed to an overall resurgence in the NASA Heliophysics flight program and system observatory.
- Restructure Solar Terrestrial Probes (STP) as a moderate-scale, principal investigator-led flight program, and implement three mid-scale missions with an eventual recommended four-year cadence. This budget supports launch of the PI-led IMAP mission in 2025. NASA selected the GLIDE SmallSat mission from the most recent STP MO announcement of opportunity, which will fly as a rideshare with IMAP. The date of the next AO has not been determined.
- Implement a large Living with a Star (LWS) mission to study Global Dynamic Coupling with a launch in 2024. In FY 2021, NASA began formulation of the Geospace Dynamics Constellation mission, with a targeted launch date no earlier than 2027. In early FY 2022, NASA made three selections for the GDC Interdisciplinary Science Team. In FY 2022, NASA will select the rest of the science team and the instruments that will fly on the GDC spacecraft.

The Decadal Survey also made recommendations related to space weather applications, addressed collectively to the relevant Government agencies. NASA has implemented the HERMES (Heliophysics Environmental & Radiation Measurement Experiment Suite) space weather instrument destined to operate on the Gateway and maintains funding for space weather applications research. NASA will continue collaborating with other agencies to improve space weather observation and forecasting capabilities.

NASA asks the Heliophysics Advisory Committee for input to ensure that our proposed programs maximize scientific productivity within the general framework established by the National Academies.

BIOLOGICAL AND PHYSICAL SCIENCES

NASA pioneers research to understand how spaceflight affects living systems in space and to prepare for future human exploration missions far from Earth. The experiments NASA conducts on the International Space Station (ISS) and other platforms examine how astronauts, plants, and animals regulate and sustain their growth in space. NASA examines processes of metabolism, reproduction, and development and studies how organisms repair cellular damage and protect themselves from infection and disease in conditions of microgravity. In addition to providing useful information on how living organisms adapt to spaceflight, the discoveries NASA makes in space have enormous implications for life on Earth. NASA also conducts research to understand the fundamental laws of the universe, as well as determine how physical systems react in spaceflight environments. This research provides basic scientific knowledge and results leading to societal benefit, including contributions to the basic understanding underlying space exploration technologies such as power generation and storage, space propulsion, life support systems, and environmental monitoring and control. All have led to improved space systems or new products on Earth.

The Decadal Survey on Biological and Physical Sciences Research in Space 2023-2032 will review the state of knowledge in the current and emerging areas of space-related biological and physical sciences research and generate consensus recommendations for a comprehensive vision and strategy for a decade of transformative science at the frontiers of biological and physical sciences research in space. The study report will help NASA define and align biological and physical sciences research to uniquely advance scientific knowledge, meet human and robotic exploration mission needs, and provide terrestrial benefits.

EARTH SCIENCE

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Earth Science Research	484.3	593.5	**534.9**	575.6	597.5	609.6	622.1
Earth Systematic Missions	773.1	749.8	**998.1**	979.3	1,061.3	1,119.6	1,034.5
Earth System Explorers	0.0	6.6	**23.4**	36.3	92.0	150.2	251.3
Earth System Science Pathfinder	286.8	391.0	**308.4**	274.8	237.5	219.3	230.4
Earth Science Data Systems	299.6	344.4	**366.1**	406.7	383.9	399.1	414.8
Earth Science Technology	83.7	91.1	**102.3**	105.9	114.1	117.7	119.0
Applied Sciences	69.0	73.5	**78.2**	81.8	102.8	106.7	109.9
Total Budget	**1,996.5**	**2,250.0**	**2,411.5**	**2,460.3**	**2,589.0**	**2,722.3**	**2,782.0**

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Earth Science

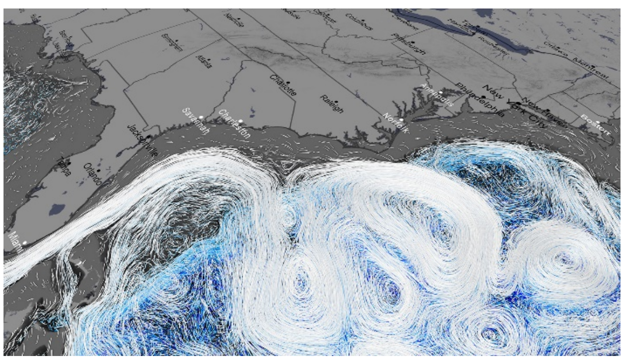
EARTH SCIENCE RESEARCH

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Earth Science Research and Analysis	352.5	409.9	**368.9**	389.6	394.2	402.7	411.0
Computing and Management	131.8	183.6	**166.0**	186.0	203.3	206.8	211.1
Total Budget	**484.3**	**593.5**	**534.9**	**575.6**	**597.5**	**609.6**	**622.1**
Change from FY 2022 Budget Request			**-58.6**				
Percent change from FY 2022 Budget Request			**-9.9%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



Ocean circulation along the US East coast generated by NASA’s ECCO (Estimating Circulation and Climate of the Ocean) data-modeling system. ECCO explains how a warming climate impacts ocean circulation, linking large-scale ocean transport to rising sea level along the U.S. eastern seaboard.

NASA’s Earth Science Research program develops a scientific understanding of Earth and its response to natural or human-induced changes. Earth is a system, like the human body, comprised of diverse components interacting in complex ways. Understanding Earth’s atmosphere, crust, water, ice, and life as a single, connected system is necessary to improve our predictions of climate, weather, and natural hazards. The Earth Science Research program addresses complex, interdisciplinary Earth science problems in pursuit of a comprehensive understanding of the Earth system. This strategy involves six interdisciplinary and interrelated science focus areas, including:

- Water and Energy Cycle: quantifying the key reservoirs and fluxes in the global water cycle, assessing water cycle change, and assessing water quality.
- Weather and Atmospheric Dynamics: enabling improved predictive capability for weather and extreme weather events.
- Earth Surface and Interior: characterizing the dynamics of the Earth’s surface and interior and forming the scientific basis for the assessment and mitigation of natural hazards and response to rare and extreme events.
- Climate Variability and Change: understanding the roles of ocean, atmosphere, land, and ice in the climate system and improving our ability to predict future changes.
- Atmospheric Composition: understanding and improving our predictive capability for changes in the ozone layer, Earth’s radiation budget, and air quality associated with changes in atmospheric composition.

EARTH SCIENCE RESEARCH

- Carbon Cycle and Ecosystems: quantifying, understanding, and predicting changes in Earth's ecosystems and biogeochemical cycles, including the global carbon cycle, land cover, and biodiversity.

NASA's Earth Science Research program pioneers the use of both space-borne and aircraft measurements in all these areas. The Earth Science Research program is critical to the advancement of the interagency United States Global Change Research Program (USGCRP), established in 1989 and mandated in the Global Change Research Act of 1990 to develop and coordinate "a comprehensive and integrated U.S. research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change." The Earth Science Research program also makes extensive contributions to international science programs, such as the World Climate Research Program.

EXPLANATION OF MAJOR CHANGES IN FY 2023

This budget request includes expanded work in the following areas:

- Wildfire-related interdisciplinary research, leveraging NASA experience and data to improve earth system predictive models and scenarios that better characterize changes in wildfire behavior across the entire life cycle;
- Greenhouse gas-related research and observations, to enhance collection of greenhouse gas data from NASA aircraft and instruments, expand existing activities under the legacy Carbon Monitoring System currently funded under the R&A program, and support GHG measurement networks; and
- A $5 million increase for the Global Learning and Observations to benefit the Environment (GLOBE) program will modernize the data infrastructure supporting the program, expand the program's reach, strengthen connections between researchers and students, and refresh educational resources. GLOBE, which received the 2021 AGU Excellence in Earth and Space Science Education Award, has been flat-funded for several years, making it difficult to update its data infrastructure and enhance programming.

This budget request reflects a reduction of $58M from the FY 2022 budget request as the FY 2022 budget contained a one-time investment in the Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) in Interdisciplinary Science and Airborne Science and a one-time investment in High End Computing Capability and Space Geodesy to accelerate hardware purchases.

ACHIEVEMENTS IN FY 2021

NASA uses satellite remote sensing as a critical tool for observing changes in water quality near coastal regions, and more recently inland, thanks to increased spatial resolution. The advent of hyperspectral sensors promises to enhance the accuracy of remotely sensed in-water products. These sensors will provide more precise retrievals of in-water constituents. Researchers funded under NASA Research Opportunities in Space and Earth Science (ROSES) grants, and the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) Science and Applications Team, utilized data from NASA's Ocean Ecology Lab. Researchers determined that retrievals of phytoplankton absorption using hyperspectral sensors may be two-to-three times more precise than those done through heritage (multispectral) ocean color algorithms. This will lead to more precise characterization of organisms such as those producing harmful algal blooms, and better quantification of biodiversity in aquatic ecosystems.

EARTH SCIENCE RESEARCH

The Raikoke volcanic eruption occurred on June 21, 2019, with ash ejected to the upper troposphere and lower stratosphere. The London Volcanic Ash Advisory Centre provided initial estimates of the plume arrival over the United Kingdom. Researchers examined the dispersion of the Raikoke volcanic plume and its impact over the UK and Europe. They documented a methodology for identifying and distinguishing between volcanic ash plumes and pyrocumulonimbus (PyroCb), an explosive storm cloud created by the smoke and heat from fire, using the Met Office Numerical Atmospheric-dispersion Modelling Environment (NAME) and observations from the UK Met Office lidar network and NASA Micro-Pulse Lidar Network (MPLNET). MPLNET is a federated network of Micro-Pulse Lidar (MPL) systems designed to measure aerosol and cloud vertical structure. The MPLNET data provided plume monitoring upwind of the UK and Europe receptor region, including data from Fairbanks Alaska, and NASA Goddard Space Flight Center (GSFC). Coupling the MPLNET data with the NAME model output and lidar observations from the UK provided sufficient information to identify and distinguish the volcanic plumes from the smoke. The study demonstrates the utility of using different lidar networks to provide operational monitoring at regional and global scales.

Researchers used observations from NASA’s A-Train to develop new constraints on rapid cloud adjustments to aerosols for evaluating and improving climate models. The A-Train is a constellation of sun-synchronous satellites that cross the equator simultaneously each afternoon. They showed that understanding the influence of aerosols on warm rain needs to be separated into two components: the influence of aerosols on drizzle formation, and the influence of aerosols on warm rain. Decomposing the problem in this way allows researchers to attribute biases in climate models to separate processes that enable them to target the appropriate physics for improvement. Biomass burning emits 34 -41 Tg (1 Tg=1 million tons) of smoke aerosol into the atmosphere annually, which directly influences the Earth’s climate by attenuation of solar and terrestrial radiation. Researchers presented the first global-scale view of smoke aerosol in the atmosphere from the NASA Atmospheric Tomography Mission (ATom). They found that biomass burning particles in the remote troposphere are dilute but ubiquitous, with dilute smoke contributing as much as denser plumes to the associated aerosol scattering, absorption, and climate impact. In addition, their measurements indicate that a high-resolution, global aerosol model overestimates biomass burning aerosol mass in the remote troposphere by over 400 percent, largely due to insufficient wet removal by in-cloud precipitation.

Interferometric Synthetic Aperture Radar (InSAR), Global Navigation Satellite System (GNSS), and Gravity Recovery and Climate Experiment (GRACE) data can remotely measure anthropogenic influences, such as ground water injection and extraction. This affects the Terrestrial Water Storage (TWS) in many regions to a large degree. A recent analysis used these data types to determine TWS changes in Beqaa Plain, Lebanon's groundwater depletion from June 2002 to April 2017. After combining satellite data with information from available hydrologic cycle models, they identified a subsidence rate of roughly 1.10 cm per year within the Zahle district because of groundwater depletion. This result is echoed by the significant drop in water level in local monitoring wells throughout the region. A different team applied new processing to InSAR data to recover three-dimensional displacement fields in the Coachella Valley. They found ground displacements of up to 12 cm in 2017 from ground water recharge. Using their new methodology, they determined that the displacement was likely associated with significant horizontal displacements that led to contraction across the fault bounding the northern side of the basin, as well as increases in right-lateral sense of strain in some areas along the fault.

During the time from July 1, 2020 to June 30, 2021, NASA's UAVSAR conducted 61 science/engineering flights totaling 290 flight hours, despite the pandemic shutdown that impacted/delayed several campaigns. Highlights of this year’s UAVSAR science campaigns included San Andreas fault monitoring and

EARTH SCIENCE RESEARCH

California landslides mapping. Scientists used the L-band observations acquired over the San Andreas fault since 2009 to generate DInSAR products and estimate Line of Sight velocity. Results reveal shallow fault slip and locking distribution and help quantify along strike surface fault creep variation. Scientists collected UAVSAR data over 134 slow-moving landslides in the northern California coast ranges to calculate 3-D velocity measurements of landslide size as well as to infer the actively deforming thickness, volume, geometric scaling, and frictional strength of each landslide. They found that the largest landslide complexes in our data set become large primarily by increasing in area rather than thickness and that the slow-moving landslides display scale-dependent frictional strength. This suggests that large landslides tend to be weaker than small landslides, mostly due to larger landslides having a larger composition of weak material. The researchers use and demonstrate the UAVSAR techniques to better understand landslide processes and quantify their contribution to landscape evolution and hazards to human safety.

Satellite multi-sensor precipitation products (SMPPs) have the potential to fill in precipitation data for various applications where surface gauge data are not sufficient, but uncertainty in the SMPPs has hampered such use. Research demonstrated how considering the uncertainty in SMPPs can improve predictions from a landslide hazard model over the mountainous southeastern United States. An error formulation model was developed using coincident Integrated Multi-satellite Retrievals for Global Precipitation Measurement (GPM) mission (IMERG) and ground-based gauge precipitation data. The data were input into a probabilistic version of NASA’s Landslide Hazard Assessment for Situational Awareness (LHASA) model. The additional uncertainty information allowed the probabilistic LHASA model to forecast more landslides than the existing deterministic version, particularly in high hazard nowcast categories.

In FY 2021, the Airborne Science project supported several joint NASA and European Space Agency (ESA) campaigns. In Europe, the NASA Airborne Visible/Infrared Imaging Spectrometer Next Generation (AVIRIS-NG) team successfully conducted a joint campaign with the ESA airborne imaging spectrometer in support of future space missions, to advance cooperation and harmonization of algorithms and products from future global imaging spectrometer missions. The effort supported the future NASA Surface Biology and Geology (SBG) mission, and the candidate European Copernicus Hyperspectral Imaging Mission for the Environment (CHIME) mission.

The GLOBE project continued and expanded its reach to teachers, students, and citizen scientists around the world by engaging them in hands-on science to better understand the Earth as a system. In FY 2021, the International Virtual Science Symposium received 242 entries from students from 20 countries. The GLOBE Science working group completed an assessment of all GLOBE protocols, with extensive community consultation. The GLOBE Diversity Equity and Inclusion working group will help with world-wide implementation of GLOBE and help make the program and even more welcoming place for all to participate in the research, education, and community events. The community selected seven members from around the world as inaugural members. The science community recognized GLOBE’s worldwide impact, as the program received the 2021 AGU Excellence in Earth and Space Science Education Award.

The Space Geodesy project continued the development and deployment of a modern network that includes the co-located next-generation Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Global Navigation Satellite System (GNSS), and Doppler Orbitography and Radiopositioning Integrated by Satellite stations. All three of NASA's new domestic VLBI antennas, located in Maryland, Hawaii, and Texas, participated in twice-weekly intensive observing sessions with the global network, demonstrating improved accuracy in earth rotation measurements. Space Geodesy

EARTH SCIENCE RESEARCH

completed the first three gimbals and the first telescope for new SLR sites, located in Maryland, Texas, and Ny-Ålesund, with the first integrated gimbal and telescope built and undergoing outdoor testing.

Both Scientific Computing and HECC projects completed the installation of major procurements – the hyperwall compute system upgrade at NASA Ames Research Center (ARC), GPGPU expansion at both ARC and GSFC, Aitken and Discover super computers expansion at ARC and GSFC, and Endeavor supercomputer replacement at ARC. Both NASA centers have increased the capacity of computing resource and expanded infrastructure and support of AI/ML applications for NASA missions. The projects also conducted investigations into “pathfinding” systems to identify architectures suitable for NASA’s applications and inform future procurements. Computational tasks completed major experiments such as CMIP6 climate projections, international DYnamics of the Atmospheric general circulation Modeled On Non-hydrostatic Domains (DYAMOND), and high-resolution coupled atmosphere-ocean "Estimating the Circulation and Climate of the Ocean" (ECCO).

WORK IN PROGRESS IN FY 2022

NASA will continue to initiate and select new awards. Notable new research program selections in FY 2022 are:

The Cryospheric Sciences program element, which will initiate 10 new investigations of polar ice, including the Antarctic and Greenland ice sheets, polar glaciers, and sea ice in the Arctic and Southern Oceans, that are based on satellite and airborne remote sensing. The program element seeks to improve our understanding of cryospheric processes, link the cryosphere to the global climate system, and/or advance predictive capabilities.

NASA selected 10 new investigations under the competition of the NASA Carbon Monitoring System (CMS) program element, which is a forward-looking initiative designed to make significant contributions in characterizing, quantifying, understanding, and predicting the evolution of global carbon sources and sinks through improved monitoring of carbon stocks and fluxes.

NASA is preparing for the second phase of the CPEX-AW investigation in collaboration with the ESA, with the primary goal of conducting a post-launch calibration and validation activities of the Atmospheric Dynamics Mission-Aeolus (ADM-AEOLUS) Earth observation wind Lidar satellite in Sal, Cabo Verde. NASA will fly the updated Doppler Aerosol WiNd lidar instrument (DAWN) instrument to test the effect that the investments made it in have on its performance. This flight, to take place aboard NASA’s DC-8, may also make under flights of the European Space Agency's Aeolus satellite, which was launched in August 2018, and also uses wind lidar to make measurements of atmospheric wind profiles. In addition to joint calibration/validation of ADM-AEOLUS, CPEX-AW will study the dynamics and microphysics related to the Saharan Air Layer, African Easterly Waves and Jets, Tropical Easterly Jet, and deep convection in the InterTropical Convergence Zone. NASA is looking to include coordinated airborne observations with NOAA in both FY 2022 and FY 2023.

Significant analysis of prior year airborne data will be conducted in FY 2022. Data will be acquired from work carried out in close collaboration with ESA (AVIRIS-NG, HyTES, and SLAP all in Europe in summer of 2021). Continuing analysis is part of the effort with ESA under the NASA/ESA joint program planning group. FY 2022 will also include analysis of EXPORTS data acquired during FY 2021. JPPG coordinated activity includes continued work on Arctic Methane Permafrost Challenge, and Ice Mass Balance Intercomparison Exercise (IMBIE-3) activity.

EARTH SCIENCE RESEARCH

The Airborne project will focus on increasing Airborne instrument development under AITT that was impacted by COVID-19. NASA expects significant testing/use of instruments from previous AITT – AirLUSI in spring, and C-HARRIER in field with S-MODE in FY 2022. The Student Airborne Research Program (SARP) continues in FY 2022 to provide airborne flights for students who could not get that experience during “Virtual SARP” in FY 2020 and FY 2021. 53 students flew projects in early December. NASA expects SARP to be back to an in-person experience in FY 2022.

Earth Science research will begin increasing minority university participation in our surface-based measurement networks, by amending ROSES 2021 following the receipt of responses to the previously published RFI. The experiment of augmenting R&A awards to support PI engagement in new applications related activities will continue in collaboration with the Applied Sciences program.

New research elements will target science of coastal resilience and hydrometeorological aspects of subseasonal-to-seasonal prediction. NASA expects these new research elements to initiate funding in areas with budget growth in FY 2022, as well as stabilize/enhance planned work on carbon monitoring and methane.

NASA’s SnowEx investigation continues to collect snow data in forested regions with airborne multi-sensor and in situ validation observations. This is a multi-year airborne and ground campaign that collects observations to enable studies for snow satellite mission designs. The goal is to develop/test algorithms for measurement of snow water equivalent in forested and non-forested areas by providing multi-sensor observations of seasonally snow-covered landscapes; develop/test energy balance models and snow distribution models of beneath-canopy snowpack using appropriate field measurements; and to explore how best to combine sensing technologies with modeling and data assimilation methods to produce the most accurate products.

GLOBE is currently working on merging the two GLOBE applications – GLOBE Observer and GLOBE Mobile Data Entry – into a single application under the GLOBE Observer name. The application will include access to all GLOBE protocols. Citizen scientists will still be able to contribute cloud, land cover, tree height, and mosquito habitat observations, but GLOBE educators will also be able to access all protocols from just one application. The team recently merged the atmosphere protocols, and the project will update hydrosphere protocols next. In response to community needs, the program is improving data entry to make it significantly easier for educators to work with students who are doing data entry from mobile devices.

Instrumentation for the first next-generation Satellite Laser Ranging (SLR) system is in preparation for delivery to Ny-Ålesund to begin installation. Space Geodesy is finalizing its 2020 International Terrestrial Reference Frame solutions for submission and evaluation by the International Earth Rotational and Reference System Service. NASA is building its first flight-ready Laser Retroreflector Arrays (LRA) for integration on the GPS-III satellites. The GPS-LRA will provide an independent tool for improved positioning, navigation, and timing to advance NASA Earth-science and partner operational objectives.

Both Scientific Computing (SC) and High End Computing Capability (HECC) projects continue the current path to expand computing and storage at NASA centers. These projects are expanding the public cloud capabilities to support open science. The centers are researching moving NASA workloads between on-premise computing centers and in-the-cloud capabilities. HECC will expand research in application development, software technology and hardware pathfinding systems. As part of the research and development efforts, HECC and SC will start a computing architecture study for the evolution of computing services to support future science and engineering efforts. SC is continuing the support of Earth information systems projects in the deployment of in-the-cloud computational environment and the porting of NASA GEOS atmospheric model to GPU based computing systems. SC and HECC are engaging in supercomputing workforce development discussion with minority serving institutions (MSIs) and Historically Black Colleges and Universities (HBCUs).

KEY ACHIEVEMENTS PLANNED FOR FY 2023

In 2023, NASA will undertake an initiative to further develop the Wildfire Earth Information System and Fire Information for Resource Management System. This initiative will mature certainty in predictive models of fire behavior, related environmental, social, economic, and human factors, and pathways to improve and sustain support for wildfire management and science through the integration of new Earth Observation datasets and robust modeling techniques. NASA will deploy existing remote sensing instruments, and test new capabilities where possible, to map fuel loading, fuel structure, and fuel moisture status to update fire vulnerability and risk management maps in the areas of the western United States where this data is most needed.

GLOBE will focus on strengthening project operations by modernizing the GLOBE website and improving the data and information system. These activities will help entice new teachers, partners, and citizen scientists to join the project. It will also ensure the underlying systems can support a growing community while improving services to the existing education and science community. The Earth Science Division will also initiate a project-level evaluation strategy. Work will begin to refresh GLOBE education materials and improve the usability of GLOBE data for Earth system science research. The project will continue to support U.S. Student Research Symposia, where GLOBE students showcase their research and receive feedback from STEM professionals. NASA plans to release a solicitation to host the GLOBE Implementation Office, as the current cooperative agreement will end in May 2024.

In FY 2023, NASA plans to conduct at least one field campaign in North America using NASA airborne instrument(s) and airborne platforms to address methane sources and analyze data to better constrain emission estimates, provide comparison information for satellite-based emissions, and provide rigorous data sets for comparisons of top-down and bottoms-up greenhouse gas emissions. NASA will enhance support of GHG-measurement networks. Surface-based networks provide important information about concentrations and can infer emission information when used together with models. NASA plans to release a new competition of the Carbon Monitoring System in ROSES 2022 that focuses more on methane than in past solicitations, which were largely, but not exclusively, CO_2 dominated.

NASA will make new selections solicited in ROSES 2022 and award them. While most of the solicitations represent the periodic solicitations of ongoing R&A programs, there are some efforts that are sufficiently different from previous years that merit mention.

NASA will release a new Interdisciplinary Science solicitation in ROSES 2022, with the selected proposals leading to new awards during FY 2023. These will emphasize ties to the Earth System Observatory. The main topics include:

- Nitrogen cycle;
- Ocean-atmosphere gas and particle exchange;
- Environmental impacts of wildfires;
- Remote sensing, urbanization, and environmental justice; and
- Land-ocean continuum.

EARTH SCIENCE RESEARCH

Salinity and Stratification at the Sea Ice Edge (SASSIE) will deploy the ship-based component. SASSIE will address its science themes in a multi-scale in situ, airborne, satellite, and modeling experiment. The primary aim of the field campaign is to capture the upper ocean structure during the transition from summer sea ice retreat to autumn sea ice advance. SASSIE will quantify the strength, size, and depth of fresh near-surface anomalies resulting from melting ice, the horizontal and vertical structure of those fresh anomalies as they evolve due to air-sea fluxes and waves, ocean currents and mixing, and the ocean conditions and the presence of sea ice as it begins to form.

The Arctic Radiation-Cloud-Aerosol-Surface Interaction Experiment (ARCSIX) investigation is in the planning stage. ARCSIX will quantify the contribution of surface properties, clouds, aerosol particles, and precipitation to the Arctic summer surface radiation budget and sea ice melt during the early melt season (May through mid-July). The investigation will be achieved by flying two aircraft simultaneously. One will collect in situ aerosol particle, cloud, atmospheric and surface properties along with radiation below, above, and inside a cloud layer, and the other will serve as a bridge to satellite observations by surveying with heritage and novel remote sensing instruments from above.

Researchers plan flights on the NASA G-V in support of the calibration/validation effort of the Surface, Water and Ocean Topography (SWOT) mission. The goal of this activity is to conduct independent validation measurements of ocean sea surface height under the SWOT track during the post-launch calibration/validation period, verifying SWOT performance over the ocean. The Modular Aerial Sensing System, an instrument developed at the Scripps Institution of Oceanography, will collect independent validation measurements. The mission anticipates performing the surveys at altitudes ranging from 600 to 4,500 feet above mean sea level, depending on atmospheric and oceanic conditions.

NASA plans to continue upgrading the Space Geodesy Satellite Laser Ranging stations and begin upgrading the Very Long Baseline Interferometry antennas at its international partner sites. Upon completion of the upgrades, NASA expects improved accuracy for precision orbit determination for missions such as ICESat-2 and GRACE-FO data products. The upgrades will continue to increase the accuracy of low-degree gravity field estimates for tracking processes such as ice sheet mass change, estimates of sea level rise rate and its acceleration such as those provided by Sentinel-6 Michael Freilich, and improve the quality of Earth orientation parameters for spacecraft navigation and measurement of the angular momentum balance among the solid Earth, ocean, and atmosphere.

SC and HECC will continue the path to expand on-premise computing and storage at NASA centers. Both computing centers will continue to expand cloud usage to support open science. NASA plans to mature the research in moving NASA computational tasks between on-premise and in-the-cloud capabilities. Based on the result of the computing architecture study completed in FY 2022, SC and HECC will start architecture evolution projects. In addition, SC and HECC plans to start investing in supercomputing workforce development at MSIs and UBCUs.

Program Elements

GLOBAL MODELING AND ASSIMILATION OFFICE

The Global Modeling and Assimilation Office creates global climate and Earth system component models using data from Earth science satellites and aircraft. Investigators can use these products worldwide to further their research.

EARTH SCIENCE RESEARCH

AIRBORNE SCIENCE

The Airborne Science project is responsible for providing aircraft systems to further science and advance the use of satellite data. NASA uses these assets worldwide in campaigns to investigate extreme weather events, observe Earth system processes, obtain data for Earth science modeling activities, and calibrate instruments flying aboard Earth science spacecraft. NASA Airborne Science platforms support mission definition and development activities. These activities include:

- Conducting instrument development flights;
- Gathering ice sheet observations as gap fillers between missions;
- Serving as technology test beds for Instrument Incubator Program missions;
- Serving as the observation platforms for research campaigns, such as those competitively selected under the suborbital portion of Earth Venture; and
- Calibrating and validating space-based measurements and retrieval algorithms.

OZONE TRENDS SCIENCE

The Ozone Trends Science project produces a consistent, calibrated ozone record used for trend analyses and other studies.

INTERDISCIPLINARY SCIENCE

Interdisciplinary Science includes science investigations as well as calibration and validation activities that ensure the utility of space-based measurements. In addition, this project supports focused fieldwork (e.g., airborne campaigns) and specific facility instruments which fieldwork depends on.

EARTH SCIENCE RESEARCH AND ANALYSIS

Earth Science Research and Analysis is the core of the research program and funds the analysis and interpretation of data from NASA’s satellites. This project funds the scientific activity needed to establish a rigorous foundation for the satellites’ data and their use in computational models.

EARLY CAREER RESEARCH

The Early Career Research project (formally named Fellowships and New Investigators) supports graduate and early career research in the areas of Earth system research, applied science, data systems, and technology.

SPACE GEODESY

Geodesy is the science of measuring Earth’s shape, gravity, orientation, and rotation and how these properties change over time. The Space Geodesy Project (SGP) encompasses the development, operation, and maintenance of a global network of space geodetic technique instruments, a data transport and collection system, data analysis, and the public dissemination of data products required to maintain a stable terrestrial reference system. SGP provides the data and analysis essential for fully realizing the measurement potential of the current and coming generation of Earth Observing spacecraft.

EARTH SCIENCE RESEARCH

EARTH SCIENCE DIRECTED RESEARCH AND TECHNOLOGY

The Earth Science Directed Research and Technology project funds the civil service staff who work on emerging Earth Science flight projects, instruments, and research.

GLOBAL LEARNING AND OBSERVATIONS TO BENEFIT THE ENVIRONMENT

Global Learning and Observations to Benefit the Environment (GLOBE) is a worldwide, hands-on primary and secondary school-based project that promotes collaboration among students, teachers, and scientists to conduct inquiry-based investigations about our environment. The program centers on the study of dynamics of Earth's environment, focused on atmosphere, hydrosphere, pedosphere (i.e., soil), and biosphere. Students take measurements, analyze data, and participate in research in collaboration with scientists. NASA initiated a citizen science component, called GLOBE Observer, in 2016 that makes four protocols available for use by anyone in a GLOBE country. NASA sponsors the GLOBE program and partners with the National Science Foundation, the National Oceanic and Atmospheric Administration, and the United States. Department of State.

For more information, go to: http://www.globe.gov

SCIENTIFIC COMPUTING

The Scientific Computing project funds NASA's Earth Science Discover supercomputing system, high-end storage, network, software engineering, and user interface projects at NASA GSFC, including climate assessment modeling and data analysis. Scientific Computing supports Earth system science modeling activities based on data collected by Earth science spacecraft. The system is separate from the High-End Computing Capability program at NASA Ames Research Center, so it can be close to the satellite data archives at GSFC. The proximity to the data and the focus on satellite data assimilation makes the Discover cluster unique in its ability to analyze large volumes of satellite data quickly. The system currently has approximately 127,000 central processing unit cores and 320,000 graphical processing unit cores.

HIGH END COMPUTING CAPABILITY

HECC focuses on the Endeavour, Pleiades, Electra, and Aitken supercomputer systems and the associated network connectivity, data storage, data analysis, visualization, and application software support. It serves the supercomputing needs of all NASA mission directorates and NASA-supported principal investigators at universities. The funding supports the operation, maintenance, upgrade, and expansion of NASA's supercomputing capability. These four supercomputer systems, with approximately 612,000 central processing unit cores and 1.2 million graphical processing unit cores, support NASA's aeronautics, human exploration, and science missions. For example, the systems are being used to perform first-of-a-kind simulations helping engineers reduce risk from acoustic vibrations generated by Orion's Launch Abort System motor. The systems also run simulations created with unprecedented resolution, helping scientists understand how galaxies co-evolve with extensive reservoirs of gas around them.

EARTH SCIENCE RESEARCH

DIRECTORATE SUPPORT

The Directorate Support project funds the NASA Science Mission Directorate's institutional and crosscutting activities including: National Academies studies, proposal peer review processes, printing and graphics, information technology, the NASA Postdoctoral Fellowship program, working group support, independent assessment studies, procurement support for the award and administration of all grants, and other administrative tasks.

Program Schedule

Date	Significant Event
Q1 FY 2022	ROSES-2021 selection within six to nine months of receipt of proposals
Q2 FY 2022	ROSES-2022 solicitation release
Q1 FY 2023	ROSES-2022 selection within six to nine months of receipt of proposals
Q2 FY 2023	ROSES-2023 solicitation release
Q1 FY 2024	ROSES-2023 selection within six to nine months of receipt of proposals
Q2 FY 2024	ROSES-2024 solicitation release
Q1 FY 2025	ROSES-2024 selection within six to nine months of receipt of proposals
Q2 FY 2025	ROSES-2025 solicitation release
Q1 FY 2026	ROSES-2025 selection within six to nine months of receipt of proposals
Q2 FY 2026	ROSES-2026 solicitation release
Q1 FY 2027	ROSES-2026 selection within six to nine months of receipt of proposals
Q2 FY 2027	ROSES-2027 solicitation release

Program Management & Commitments

Program Element	Provider
Global Modeling and Assimilation Office	Provider: Various Lead Center: HQ Performing Center(s): GSFC Cost Share Partner(s): N/A
Airborne Science	Provider: Various Lead Center: HQ Performing Center(s): AFRC, ARC, WFF, JSC, LaRC Cost Share Partner(s): N/A

EARTH SCIENCE RESEARCH

Program Element	Provider
Scientific Computing	Provider: GSFC Lead Center: HQ Performing Center(s): GSFC Cost Share Partner(s): N/A
Ozone Trends Science	Provider: Various Lead Center: HQ Performing Center(s): LaRC, GSFC Cost Share Partner(s): USGCRP and SOST agencies
Interdisciplinary Science	Provider: Various Lead Center: HQ Performing Center(s): HQ, JPL, GSFC, ARC, AFRC, GRC, LaRC, MSFC, JSC Cost Share Partner(s): USGCRP and SOST agencies
Earth Science Research and Analysis	Provider: Various Lead Center: HQ Performing Center(s): All NASA Centers Cost Share Partner(s): USGCRP and SOST agencies
High-End Computing Capability	Provider: ARC Lead Center: HQ Performing Center(s): ARC Cost Share Partner(s): N/A
Directorate Support	Provider: Various Lead Center: HQ Performing Center(s): All NASA Centers Cost Share Partner(s): N/A
Early Career Research	Provider: Various Lead Center: HQ Performing Center(s): All NASA Centers Cost Share Partner(s): N/A
Space Geodesy	Provider: Various Lead Center: GSFC Performing Center(s): GSFC, JPL Cost Share Partners: N/A
Global Learning and Observations to Benefit the Environment	Provider: University Corporation for Atmospheric Research Lead Center: HQ Performing Center(s): HQ, GSFC Cost Share Partner(s): N/A

EARTH SCIENCE RESEARCH

Acquisition Strategy

NASA implements the Earth Science Research program via competitively selected research awards. NASA releases research solicitations each year in the ROSES NASA Research Announcements. All proposals in response to NASA ROSES are peer reviewed and selected based on defined criteria. The program competitively awards funds to investigators from academia, the private sector, NASA centers, and other Government agencies.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Relevance	Earth Science Advisory Committee	2021	To review progress towards Earth Science objectives in the NASA Strategic Plan	All six science focus areas remained on track towards the achieving both Earth Science annual performance goals	2022; annually
Relevance	Earth Science Advisory Committee	2022	To review progress towards Earth Science objectives in the NASA Strategic Plan	TBD	2023; annually

EARTH SYSTEMATIC MISSIONS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Surface Water and Ocean Topography Mission (SWOT)	68.9	27.8	**47.5**	10.5	10.6	6.5	6.5
NASA-ISRO Synthetic Aperture Radar (NISAR)	90.8	58.0	**58.6**	29.0	25.0	14.9	16.5
Sentinel-6	8.0	22.8	**40.3**	63.9	55.2	25.6	8.7
Plankton, Aerosols, Clouds, ocean Ecosystem (PACE)	145.1	81.9	**112.8**	73.3	20.9	22.3	7.5
Other Missions and Data Analysis	460.4	559.4	**739.0**	802.7	949.5	1,050.3	995.3
Total Budget	**773.1**	**749.8**	**998.1**	**979.3**	**1,061.3**	**1,119.6**	**1,034.5**
Change from FY 2022 Budget Request			**248.3**				
Percent change from FY 2022 Budget Request			**33.1%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

This image shows the fully integrated SWOT observatory currently undergoing testing in France in collaboration with mission partner CNES, in preparation for planned launch in November 2022.

The Earth Systematic Missions (ESM) program includes a broad range of multi-disciplinary science investigations aimed at understanding the Earth system and its response to natural and human-induced forces and changes. Understanding these forces will help determine how to predict future changes and mitigate or adapt to these changes.

The ESM program develops Earth-observing satellite missions, manages the operation of these missions once on-orbit, and produces data products to support the research and applications communities.

Interagency and international partnerships are central elements of the ESM program. More than half of the projects in development under ESM have an international or interagency contribution, and several on-orbit missions provide data products in near real-time for use by the United States and international meteorological agencies and disaster responders.

EARTH SYSTEMATIC MISSIONS

EXPLANATION OF MAJOR CHANGES IN FY 2023

This budget request includes renaming "Decadal Survey Future Missions" to "Earth System Observatory Future Missions" and establishing "Sustained Climate Observations Future Missions" as a new project to address sustained measurements of climate-related variables, potentially through interagency or international collaborations. The new project includes $3 million to explore options for future space-based measurements of greenhouse gases. Additional funding is provided to ramp up current development missions, such as SWOT, Sentinel 6, PACE, and missions in formulation to include Sustainable Land Imaging and Earth System Observatory missions.

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

FY 2023 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027	BTC	Total
Formulation	136.8	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	136.8
Development/Implementation	512.6	68.9	27.8	**29.8**	0.0	0.0	0.0	0.0	0.0	639.0
Operations/Close-out	0.0	0.0	0.0	**17.7**	10.5	10.6	6.5	1.4	0.0	46.7
2022 MPAR LCC Estimate	**649.4**	**68.9**	**27.8**	**47.5**	**10.5**	**10.6**	**6.5**	**1.4**	**0.0**	**822.4**
Total Budget	**649.4**	**68.9**	**27.8**	**47.5**	**10.5**	**10.6**	**6.5**	**6.5**	**0.0**	**827.5**
Change from FY 2022 Budget Request				**19.7**						
Percent change from FY 2022 Budget Request				**70.9%**						

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The 2022 MPAR LCC Estimate reflects the Fiscal Year 2022 Quarter 1 Financial Report, which is current as of December 2021. The requested budget authority is the project's current budget requirements which have seen programmatic changes approved by NASA since December 2021.

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

An artist's concept shows the Surface Water Ocean Topography (SWOT) satellite, which entered the implementation phase in May 2016. SWOT will make high-resolution, wide-swath altimetric measurements of the world's oceans and freshwater bodies to understand their circulation, surface topography, and storage. This multi-disciplinary, cooperative international mission will produce science and data products that will allow for fundamental advances in understanding the global water cycle.

PROJECT PURPOSE

The Surface Water and Ocean Topography (SWOT) mission will improve our understanding of the world's oceans and terrestrial surface waters. The mission will make high-resolution measurements of ocean circulation, its kinetic energy, and its dissipation, through broad swath altimetry. These measurements will improve ocean circulation models and predictions of weather and climate. The mission will also revolutionize knowledge of the surface water inventory on the continents by making precise measurements of water levels in millions of lakes and water bodies and the discharge of all major rivers. This will allow for deeper understanding of the natural water cycle and potentially better water management.

The 2007 and 2017 National Academies decadal surveys endorsed SWOT. The mission will complement the Jason oceanography missions, as well as other NASA missions currently in operation and development to measure the global water cycle: Sentinel-6, Global Precipitation Measurement, Soil Moisture Active Passive, and Gravity Recovery and Climate Experiment Follow-On.

SWOT is a collaborative mission with the Centre National d'Études Spatiales (CNES), Canadian Space Agency (CSA), and United Kingdom Space Agency (UKSA).

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

PROJECT PARAMETERS

SWOT will provide broad-swath sea surface heights and terrestrial water heights for at least 90 percent of the globe using a dual-antenna Ka-band Radar Interferometer (KaRIn). The SWOT payload will also include a precision orbit determination system consisting of Global Positioning System-Payload (GPSP), Doppler Orbitography and Radio positioning Integrated by Satellite (DORIS) receivers, and a Laser Retro-reflector Assembly (LRA). In addition, SWOT carries a Nadir Altimeter and a radiometer for tropospheric path delay corrections. NASA will provide a radiometer designed to determine tropospheric water vapor content, the GPSP system to complement DORIS for precise positioning of the satellite, and a

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

backscattering laser for precise calibration of the other instruments. CSA will provide a key component of the radar instrument – a set of Extended Interaction Klystrons (EIKs). CNES will provide one of the two elements of the KaRIn radar Radio-Frequency Unit (RFU), the Poseidon-3C Ku-/C-band Nadir altimeter, and the DORIS precise orbit determination system. UKSA will provide the other element of the KaRIn radar RFU and support mission science and applications that will strengthen the international collaborations of the mission. SWOT's prime mission is three years.

ACHIEVEMENTS IN FY 2021

The SWOT project completed integration and testing of the KaRIn instrument, including the CNES-supplied RFU and CSA-supplied EIKs; the nadir payload module, including the Advanced Microwave Radiometer-C (AMR-C) and LRA; and the integrated Payload Module (PM), including the KaRIn and nadir payload modules. Following delivery of the PM to CNES, Jet Propulsion Laboratory (JPL) and the CNES spacecraft subcontractor, Thales Alenia Space, initiated observatory integration and testing.

WORK IN PROGRESS IN FY 2022

The SWOT project will complete observatory integration and testing and prepare it for shipment to the Vandenberg Space Force Base and initiate mating with the SpaceX Falcon-9 launch vehicle. The SWOT project will prepare the mission operations and ground systems to support the post-launch spacecraft operations and science data processing.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

The SWOT project will complete mating of the observatory with the SpaceX Falcon-9 launch vehicle and conduct the launch. The SWOT project will subsequently commission and conduct calibration/validation of the satellite bus and science payload and initiate science operations producing science data products.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2023 PB Request
KDP-C	May 2016	May 2016
CDR	Feb 2018	May 2018
KDP-D	Oct 2019	Apr 2021
Launch	Apr 2022	Jun 2023
Start Phase E	Oct 2022	Dec 2023

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

Milestone	Confirmation Baseline Date	FY 2023 PB Request
End of Prime Mission	Oct 2025	Dec 2026

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2017	571.5	>70%	2022	639.0	12%	Launch Readiness Date (LRD)	Apr 2022	Jun 2023	+14

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**571.5**	**639.0**	**+67.5**
Aircraft/Spacecraft	0	0	0
Payloads	181.6	355.9	+174.3
Systems I&T	4.9	10.1	+5.2
Launch Vehicle	131.3	107.8	-23.5
Ground Systems	34.7	30.8	-3.9
Science/Technology	46.7	49.8	+3.1
Other Direct Project Costs	172.3	84.6	-87.7

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

Project Management & Commitments

The Earth Systematic Missions program at JPL has program management responsibility for SWOT, and NASA assigned project management responsibility to JPL. SWOT is a partnership mission between NASA, CNES, CSA, and UKSA.

Element	Description	Provider Details	Change from Baseline
KaRIn	Makes swath measurements of sea surface topography and lake and river heights	Provider: NASA, CNES, CSA, UKSA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): CNES (RFU - Digital), CSA (EIK), UKSA (RFU - Duplexer)	N/A
AMR	Provides wet tropospheric delay correction of KaRIn	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
GPSP	Provides orbit determination	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
LRA	Provides orbit determination	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
X-band Telecom	Provides downlink of science data	Provider: L-3, Tesat Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Nadir Altimeter	Measures Jason-heritage ocean surface topography at nadir	Provider: CNES Lead Center: None Performing Center(s): None Cost Share Partner(s): CNES	N/A

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
DORIS	Provides orbit determination	Provider: CNES Lead Center: None Performing Center(s): None Cost Share Partner(s): CNES	N/A
Spacecraft Bus	Provides instrument platform	Provider: CNES Lead Center: None Performing Center(s): None Cost Share Partner(s): CNES	N/A
Launch Vehicle	Delivers spacecraft to orbit	Provider: SpaceX Lead Center: KSC Performing Center(s): None Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: Travel, logistics, and work protocols change and/or escalate at JPL and/or France due to the COVID-19 pandemic, Then: Completion and delivery of the Observatory may be delayed per the project re-plan resulting in impacts to schedule and cost reserves.	The project is developing and implementing mitigation measures in coordination with CNES and Thales to increase schedule margins by advancing the completion and delivery of the Observatory; setting up a core resident team in France to avoid travel logistics issues; setting up remote operations capabilities for some operations; cross-training teams; and proactively preparing a team safety and training plan.

Acquisition Strategy

The acquisition strategy for SWOT leveraged Jason heritage by using JPL legacy instrument designs (AMR, GPSP, and LRA) and in-house build with a combination of sole source and competitive procurements. The KaRIn leverages the Earth Science Technology Office investments and is an in-house development. The X-band Telecom was a competitive procurement. NASA selected SpaceX to provide a Falcon 9 launch vehicle through a competitive Launch Service Task Order evaluation under the NASA Launch Services II contract.

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
X-band Telecom	L3 for modulator, Tesat for traveling wave tube amplifiers	San Diego, CA Backnang, Germany
Launch Vehicle	SpaceX	Los Angeles, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Strategic Review Board (SRB)	May 2014	Systems Requirement Review (SRR) / Mission Definition Review (MDR)	Successful	Apr 2016
Performance	SRB	Apr 2016	Preliminary Design Review (PDR)	Successful	May 2018
Performance	SRB	May 2018	Critical Design Reviews (CDR)	Successful	Mar 2021
Performance	SRB	Mar 2021	System Integration Review (SIR)	Successful	Jul 2022
Performance	SRB	Jul 2022	Operational Readiness Review (ORR)	TBD	N/A

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

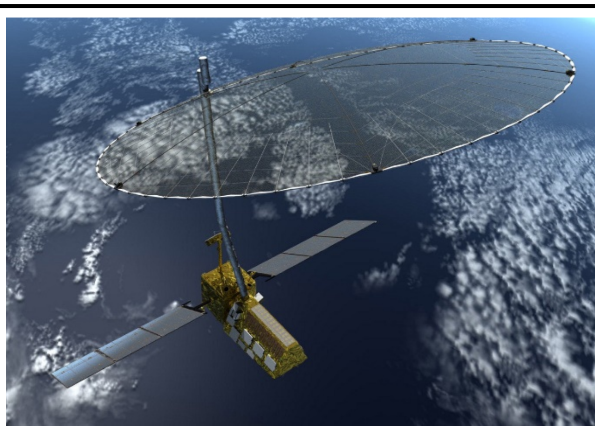
FY 2023 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027	BTC	Total
Formulation	117.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	117.0
Development/Implementation	605.6	86.3	49.5	**32.9**	0.0	0.0	0.0	0.0	0.0	774.3
Operations/Close-out	0.0	0.0	0.0	**16.7**	25.9	21.1	14.9	1.3	0.0	79.9
2022 MPAR LCC Estimate	**722.6**	**86.3**	**49.5**	**49.6**	**25.9**	**21.1**	**14.9**	**1.3**	**0.0**	**971.2**
Total Budget	**743.6**	**90.8**	**58.0**	**58.6**	**29.0**	**25.0**	**14.9**	**16.5**	**0.0**	**1,036.4**
Change from FY 2022 Budget Request				**0.6**						
Percent change from FY 2022 Budget Request				**1.0%**						

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The 2022 MPAR LCC Estimate reflects the Fiscal Year 2022 Quarter 1 Financial Report, which is current as of December 2021. The requested budget authority is the project's current budget requirements which have seen programmatic changes approved by NASA since December 2021.



The NISAR satellite (depicted here) is a joint mission between NASA and the Indian Space Research Organization (ISRO) and will be the first radar imaging satellite to use dual frequencies. NISAR will observe and take measurements of some of the planet's most complex processes, including ecosystem disturbances, ice-sheet collapse, and natural hazards.

PROJECT PURPOSE

The NASA-ISRO Synthetic Aperture Radar (NISAR) mission will provide an unprecedented, detailed view of the Earth using advanced radar imaging and a dual frequency (L-band and S-band) Synthetic Aperture Radar (SAR). NISAR will be NASA's first dual frequency radar imaging satellite and will observe and measure some of the Earth’s most complex processes, including ecosystem disturbances, ice sheet collapse, and natural hazards (e.g., earthquakes, tsunamis, volcanoes, and landslides). The mission will reveal information about the evolution and state of Earth’s crust, broaden scientific understanding of our planet's changing processes and their effect on Earth's climate, and aid future resource and hazard management.

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

Both the 2007 and 2017 Earth Science Decadal Surveys endorsed the NISAR science objectives. NISAR is a collaborative mission with the Indian Space Research Organization (ISRO).

EXPLANATION OF MAJOR CHANGES IN FY 2023

The NISAR project identified a significant electro-magnetic interface issue with the ISRO-provided S-SAR after integrating with the L-SAR. The diagnosis and proposed resolution of this issue may add additional schedule and further cost growth. NASA is taking necessary steps to minimize the cost and schedule impact and will continue to report on mitigation approaches.

PROJECT PARAMETERS

NISAR consists of a dual frequency (L-band and S-band) SAR. NASA will provide the L-band SAR (L-SAR), the engineering payload, the payload integration, and payload operations. ISRO will provide S-band SAR (S-SAR), the spacecraft bus, the launch vehicle, observatory integration and testing, and spacecraft operations. NISAR has a prime mission of three years.

NISAR will implement enhanced data acquisition and data downlink capability as well as a global soil moisture product for agricultural, forest, and modeling efforts, as recommended by the interagency Satellite Needs Working Group (SNWG) process (a function of the U.S. Group on Earth Observations). The SNWG identified multiple other agencies that would benefit from NISAR systematically collecting data over North America in Quad-pol 40-megahertz mode, thus requiring additional data acquisition and downlink capability. NASA will track the cost of these additional capabilities outside of the Agency Baseline Commitment for cost, as the scope enhancements were approved after mission confirmation.

ACHIEVEMENTS IN FY 2021

The NISAR project team continued and completed the development activities of the L-SAR and the engineering payload at the JPL, while maintaining "safe at work" protocols during FY 2021. NISAR successfully completed system integration review in October 2020. Following delays due to the COVID-19 outbreak in India in 2020, ISRO delivered the fully tested S-SAR to JPL in March 2021, a delay of more than a year from the commitment made by ISRO at the KDP-C. In August 2021, ISRO delivered the baseband data handler, which handles data transfer from the S-SAR to the solid-state recorder, provided by NASA. The S-SAR completed stand-alone testing, and system integration and test of the L+S-SAR began at JPL in FY 2021. NISAR breached the Agency baseline commitment for development cost and launch readiness date (LRD) due to several factors which included ISRO hardware delivery delay, COVID -19 impacts at JPL and technical challenges encountered during L-SAR development. NASA sent the Breach notification to Congress in February 2021. NASA approved additional funding for NISAR to continue development activities and formally established the new Agency total for cost and LRD for NISAR at KDP-D in March 2021.

NISAR entered Phase D of its life cycle upon successfully completing the KDP-D. This KDP review incorporated the new Agency total cost that exceeds the baseline development cost by more than 15

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

percent. The revised launch readiness date that is more than a six-month delay from the launch readiness date set at the confirmation review.

WORK IN PROGRESS IN FY 2022

The project continues system integration and test of the L-SAR, S-SAR, the engineering payload, and the baseline data handler at JPL. The project will integrate the fully tested radar antenna and boom with the assembly during a later phase of the system integration and test activities. NISAR suffered schedule delays beginning late in FY 2021 due to efforts to investigate and resolve an electromagnetic interference issue while testing simultaneous operation of the L-SAR and S-SAR. The diagnosis and proposed resolution of this issue may add additional schedule and further cost growth. A subset team of the standing review board reviewed several mitigation options. NASA authorized the standing review board-recommended mitigation of replacing an ISRO-provided hardware box inside S-SAR. The replacement operation took place in November 2021 and the radar payload was returned to system integration and testing.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

The project will continue and complete system integration and testing of the entire payload (L-SAR, S-SAR, engineering payload and baseline data handler) along with the reflector and boom assembly in FY 2023. The project will deliver the fully integrated and tested payload to ISRO for integration with the ISRO-provided spacecraft bus.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2023 PB Request
Key Decision Point (KDP-C)	Aug 2016	Aug 2016
Critical Design Reviews (CDR)	Oct 2018	Oct 2018
Key Decision Point (KDP-D)	Dec 2019	Mar 2021
Payload Delivery to ISRO	Feb 2021	Mar 2022
Launch Readiness Date (LRD)	Sep 2022	Sep 2023

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2017	661.0	>70%	2022	774.3	+17%	LRD	Sep 2022	Sep 2023	+12

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**661.0**	**774.3**	**+113.3**
Aircraft/Spacecraft	77.1	131.8	+54.7
Payloads	211.1	328.6	+117.5
Systems I&T	23.0	44.9	+21.9
Launch Vehicle	0.6	0.2	-0.4
Ground Systems	72.6	90.0	+17.4
Science/Technology	28.2	33.3	+5.1
Other Direct Project Costs	248.4	145.5	-102.9

Project Management & Commitments

The Earth Systematic Missions program at NASA Goddard Space Flight Center (GSFC) has program management responsibility for NISAR. NASA assigned project management responsibility to JPL. NISAR is a partnership between NASA and ISRO.

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
L-SAR	Radar imaging payload	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
S-SAR	Radar imaging payload	Provider: ISRO Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ISRO	N/A
Spacecraft	Provides platform for the payload	Provider: ISRO Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ISRO	N/A
Launch Vehicle	Geosynchronous Satellite Launch Vehicle (GSLV); delivers observatory to orbit	Provider: ISRO Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ISRO	N/A

Project Risks

Risk Statement	Mitigation
If: The Reflector Deployment operations is not successful, Then: The observatory will not function as planned.	The project will exercise and test the critical functionality during system integration and test activities and risk is retired before launch.
If: The Boom Deployment operation is not successful, Then: The observatory will not function as planned.	The project will exercise and test the critical functionality during system integration and test activities and risk is retired before launch.

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

Acquisition Strategy

The design and build of L-SAR radar will be an in-house build at JPL with competed subcontracts.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Solid State Recorder	Airbus	Germany
Reflector Antenna	Astro Aerospace	California

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Strategic Review Board (SRB)	Dec 2014	Systems Requirement Review (SRR) / Mission Design Review (MDR)	Successful	Jun 2016
Performance	SRB	Jun 2016	Preliminary Design Review (PDR)	Successful	Oct 2018
Performance	SRB	Oct 2018	Critical Design Reviews (CDR)	Successful	Oct 2020
Performance	SRB	Oct 2020	System Integration Review (SIR)	Successful	Dec 2022
Performance	SRB	Dec 2022	Operational Readiness Review (ORR)	TBD	N/A

SENTINEL-6

Formulation	Development	Operations

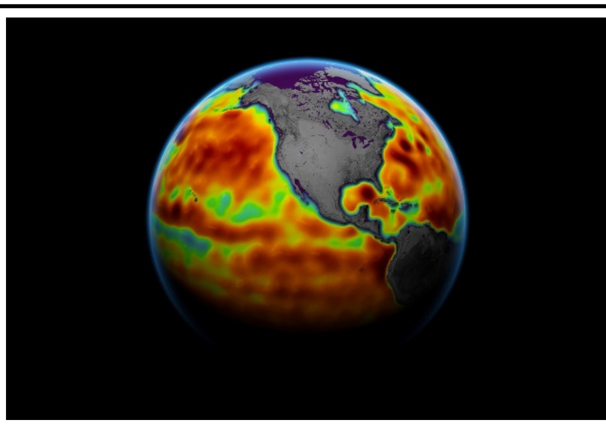
FY 2023 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027	BTC	Total
Formulation	15.5	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	15.5
Development/Implementation	214.7	7.5	13.6	**34.1**	60.4	49.0	23.1	0.0	0.0	402.3
Operations/Close-out	0.0	0.5	9.2	**6.2**	3.5	6.2	2.5	8.7	30.7	67.5
2022 MPAR LCC Estimate	**230.1**	**8.0**	**22.8**	**40.3**	**63.9**	**55.2**	**25.6**	**8.7**	**30.7**	**485.2**
Total Budget	**230.1**	**8.0**	**22.8**	**40.3**	**63.9**	**55.2**	**25.6**	**8.7**	**30.7**	**485.2**
Change from FY 2022 Budget Request				**17.5**						
Percent change from FY 2022 Budget Request				**76.8%**						

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The 2022 MPAR LCC Estimate reflects the Fiscal Year 2022 Quarter 1 Financial Report, which is current as of December 2021. The requested budget authority is the project's current budget requirements which have seen programmatic changes approved by NASA since December 2021.



This map shows sea level measured by the Sentinel-6 Michael Freilich satellite (June 2021). Red areas show higher than normal and blue areas indicate lower than normal sea level. The satellite is fully operational, producing high quality measurement products that are meeting user requirements.

PROJECT PURPOSE

The Sentinel-6 mission will provide continuity of ocean topography measurements beyond the Topography Experiment (TOPEX)/Poseidon (launched in 1992), Jason-1 (2001), Ocean Surface Topography Mission/Jason-2 (2008), and Jason-3 (2016) missions. The Sentinel-6 mission consists of two satellites, Sentinel-6 Michael Freilich and Sentinel-6B, that will launch approximately five years apart (2021 for Sentinel-6 Michael Freilich and 2026 for Sentinel-6B) to extend measurement continuity for at least another decade. This mission will serve both the operational user community and the scientific community by enabling the continuation of multi-decadal ocean topography

SENTINEL-6

Formulation	Development	Operations

measurements for ocean circulation and climate studies.

As a secondary mission objective, Sentinel-6 will characterize atmospheric temperature and humidity profiles by measuring bending angles of Global Navigation Satellite System (GNSS) signals occulted by the Earth's atmosphere. The project will process these measurement products on Earth within a few hours of acquisition on-board the satellite and make them available for incorporation into National Weather Service models to support weather forecasting capabilities.

Sentinel-6 is a collaborative mission with the National Oceanic and Atmospheric Administration (NOAA), the European Space Agency (ESA), and the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT).

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

PROJECT PARAMETERS

NASA will provide the launch vehicle and launch services as well as a set of three instruments for each of the Sentinel-6 spacecraft. These two sets of instruments are Advanced Microwave Radiometer-Climate Quality (AMR-C), the GNSS-Radio Occultation (GNSS-RO) receiver, and the Laser Reflector Array (LRA). Additionally, NASA will provide support for instrument integration and testing on the satellites, mission operations support for the NASA-developed instruments, an operational AMR-C science data processor for EUMETSAT, near real-time and offline data processing for GNSS-RO data, and mission data product archiving and distribution. The Sentinel-6 Michael Freilich and Sentinel-6B observatories each have a five-and-a-half-year prime mission.

ACHIEVEMENTS IN FY 2021

NASA successfully launched the first of two Sentinel-6 spacecraft and Sentinel-6 Michael Freilich on November 21, 2020. The Sentinel 6-MF spacecraft flies in the same orbit as the Jason-3 satellite that allowed for a thorough commissioning phase that successfully checked out all systems and performed a detailed cross-calibration between the two missions. The project team and the validation team, a panel of several dozen independent scientists and engineers, carried out a detailed independent assessment of the Sentinel-6-MF science data products. The validation team held its second meeting in May 2021 to assess the quality of the near real time data and found it to be of excellent quality that met all science requirements. The Sentinel-6 project released the near real time data to the public in June 2021 and it is widely being utilized for operational and research applications domestically (with users such as NOAA and the US Navy) and internationally.

SENTINEL-6

Formulation	Development	Operations

WORK IN PROGRESS IN FY 2022

Sentinel-6 continues to produce high-accuracy research-quality science data products. The validation team met in October 2021 to assess the quality of these products. Results show the data met requirements and the validation team and project scientists are recommending the public release of the data. In addition, the project and science teams will continue to analyze and perform detailed cross-calibration of the Sentinel-6-MF science data products with Jason-3 to ensure continuity of the sea level record. Once the teams establish this in March 2022, the Jason-3 satellite moves to an alternate orbit to continue additional synergistic science maximizing the global temporal and spatial coverage of the world's ocean.

The Sentinel-6 project will complete Integration and Test (I&T) of the second satellite (S6-B) in May 2022 and place it in storage until mid-2025 to prepare for a planned launch in November 2026. The Sentinel-6-B I&T will consist of the same sequence of activities as for the Sentinel-6-MF, conducting an electrical and mechanical integration of the Sentinel-6B and a comprehensive set of functional, performance and environmental testing. NASA will initiate the Sentinel-6B launch service acquisition process through its Launch Services Program (LSP). The Sentinel-6-B satellite development and I&T enjoy significant efficiencies in cost and schedule based on the design commonality with Sentinel-6-MF, ensuring a multi-decadal continuity of operational and science data products for the global community.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

Once the commissioning phase ends and the cross-calibration between Jason-3 and Sentinel-6-MF is complete in March 2022, Sentinel-6-MF is established as the reference altimetry mission. It will provide the most accurate record of global sea level rise - a key impact and indicator of human caused climate change. The Sentinel-6 project will continue to support development and release of data products that allow for climate monitoring, oceanographic and climate research, as well as forecasts of marine weather and hurricanes, and numerical weather prediction.

The Sentinel-6 project, in coordination with its partners, will continue mission operations of the Sentinel-6-MF satellite and monitor the health of the Sentinel-6-B satellite in storage. NASA will complete the Sentinel-6B launch service acquisition process through its LSP in preparation for a launch in November 2025.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2023 PB Request
Key Decision Point (KDP-C)	Apr 2017	Apr 2017
CDR	Oct 2017	Oct 2017
Sentinel-6 Michael Freilich U.S. Payload delivery to ESA	Mar 2020	Mar 2020
Sentinel-6B U.S. Payload delivery to ESA	Oct 2020	Oct 2020

SENTINEL-6

Formulation	Development	Operations

Milestone	Confirmation Baseline Date	FY 2023 PB Request
Launch (Sentinel-6 Michael Freilich)	Nov 2021	Nov 2020
Start Phase E (Sentinel-6 Michael Freilich)	Feb 2022	Feb 2021
End Prime Mission (Sentinel-6 Michael Freilich)	Aug 2027	Aug 2026
Launch (Sentinel-6B)	Nov 2026	Nov 2026
Start Phase E (Sentinel-6B)	Feb 2027	Feb 2027
End Prime Mission (Sentinel-6B)	Aug 2032	Aug 2032

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2017	465.9	>70 %	2022	402.3	-14%	LRD of Sentinel-6 Michael Freilich	Nov 2021	Nov 2020	-12
N/A	N/A	N/A	N/A	N/A	N/A	LRD of Sentinel-6B	Nov 2026	Nov 2026	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**465.9**	**402.3**	**-63.6**
Aircraft/Spacecraft	0	0	0
Payloads	65.8	77.2	+11.4

SENTINEL-6

Formulation	Development	Operations

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
Systems I&T	8.8	6.2	-2.6
Launch Vehicle	280.7	248.1	-32.6
Ground Systems	9.7	14.0	+4.3
Science/Technology	4.4	20.2	+15.8
Other Direct Project Costs	96.5	36.6	-59.9

Project Management & Commitments

The Earth Systematic Missions Program at the Jet Propulsion Laboratory (JPL) has program management responsibility for Sentinel-6. NASA also assigned project management responsibility to JPL. Sentinel-6 is a partnership with NOAA, ESA, and EUMETSAT.

Element	Description	Provider Details	Change from Baseline
AMR-C	Provides high spatial resolution wet tropospheric path delay corrections for the ESA-supplied Ku/C-Band Altimeter	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
GNSS-RO	Supports secondary mission objectives for weather modeling and forecasting	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
LRA	Provides orbit determination	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Ku/C-Band Altimeter	Measures Jason-heritage ocean surface topography at nadir	Provider: ESA Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ESA	N/A

SENTINEL-6

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS)	Provides orbit determination	Provider: ESA Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Spacecraft Bus	Provides instrument platform	Provider: ESA Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Launch Vehicle	Delivers spacecraft to orbit	Provider: NASA Lead Center: JPL Performing Center(s): Kennedy Space Center (KSC) Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: The launch environments for the Sentinel-6B spacecraft are different than for Sentinel-6 Michael Freilich due to changes in the selected launch vehicle, Then: The project will need to do additional testing or analysis to ensure compatibility of the spacecraft with the launch vehicle.	NASA will require the qualification test levels used for the Sentinel-6 Michael Freilich spacecraft as a spacecraft-specific requirement during the Sentinel-6B launch service acquisition process. The LSP will monitor the development of new candidate launch vehicles and evolution of existing launch vehicles to ensure compliance with the known Sentinel-6 spacecraft capabilities.

Acquisition Strategy

Sentinel-6 leverages Jason heritage by using JPL legacy instrument designs (e.g., AMR-C, GNSS-RO, and LRA) and an in-house build with a combination of sole source and competitive procurements. NASA selected SpaceX to provide a Falcon 9 launch vehicle through a competitive Launch Service Task Order evaluation under the NASA Launch Services II contract.

SENTINEL-6

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
GNSS-RO Electronics	MOOG	Golden, CO
AMR-C Antenna	Northrop Grumman Innovation Systems	San Diego, CA
LRA	ITE	Laurel, MD
Launch Services	SpaceX	Los Angeles, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Oct 2017	Critical Design Reviews (CDR)	Successful	Apr 2019
Performance	SRB	Apr 2019	Project System Integration Review (P-SIR)	Successful	Sep 2021
Performance	SRB	Sep 2020	Sentinel-6 Michael Freilich ORR	Successful	Aug 2026
Performance	SRB	Aug 2026	Sentinel-6B ORR	TBD	N/A

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	**Development**	Operations

FY 2023 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027	BTC	Total
Formulation	260.3	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	260.3
Development/Implementation	239.9	145.1	81.9	**112.8**	52.6	0.0	0.0	0.0	0.0	632.3
Operations/Close-out	0.0	0.0	0.0	**0.0**	20.7	20.9	22.3	7.5	0.0	71.4
2022 MPAR LCC Estimate	**500.2**	**145.1**	**81.9**	**112.8**	**73.3**	**20.9**	**22.3**	**7.5**	**0.0**	**964.0**
Total Budget	**500.2**	**145.1**	**81.9**	**112.8**	**73.3**	**20.9**	**22.3**	**7.5**	**0.0**	**964.0**
Change from FY 2022 Budget Request				**30.9**						
Percent change from FY 2022 Budget Request				**37.7%**						

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The 2022 MPAR LCC Estimate reflects the Fiscal Year 2022 Quarter 1 Financial Report, which is current as of December 2021. The requested budget authority is the project's current budget requirements which have seen programmatic changes approved by NASA since December 2021.

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	Development	Operations

PACE (depicted here) will advance the assessment of ocean health by measuring the distribution of phytoplankton, tiny plants and algae that sustain the marine food web. It will also continue systematic records of key atmospheric variables associated with air quality and Earth's climate.

PROJECT PURPOSE

The Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission will improve our understanding of how the ocean and atmosphere exchange carbon dioxide. In addition, it will reveal how aerosols might fuel phytoplankton growth in the surface ocean. PACE's unprecedented spectral coverage will provide the first-ever global measurements designed to identify phytoplankton community composition. This will significantly improve our ability to understand Earth's changing marine ecosystems, manage natural resources (e.g., fisheries), and identify harmful algal blooms.

PACE's primary sensor, the Ocean Color Instrument (OCI), is a highly advanced optical spectrometer that will measure properties of light over portions of the electromagnetic spectrum extending key ocean color data records. The interaction of sunlight with substances or particles in seawater such as chlorophyll, a green pigment found in most phytoplankton species, determine the color of the ocean. By monitoring global phytoplankton distribution and abundance with unprecedented detail, through measurement of ocean color, OCI will help us improve our understanding of the complex systems that drive ocean ecology.

PACE includes two contributed polarimeters to measure how the oscillation of sunlight within a geometric plane - known as its polarization - changes by passing through clouds, aerosols, and the ocean. Measuring polarization states of UV-to-shortwave light at various angles provides detailed information on the atmosphere and ocean (e.g., particle size and composition).

EXPLANATION OF MAJOR CHANGES IN FY 2023

PACE completed its replan in November 2021 to address COVID-19 impacts for the delays and residual inefficiencies associated with the gradual return to work, as well as technical challenges. This budget request reflects the updated estimates and budget profile for the cost of completing the mission. While the funding profile was adjusted to reflect the replan, there was no increase in the total mission budget. The updated budget profile total now supports an LRD date of May 2024, a schedule delay of 4 months from the baseline commitment.

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	Development	Operations

PROJECT PARAMETERS

PACE is a design-to-cost mission, and NASA approved the baseline cost, mission requirements, and mission architecture at confirmation. The NASA Goddard Space Flight Center (GSFC) is responsible for the design and fabrication of the spacecraft, development of the ocean color instrument (OCI), and development of the mission operations center. GSFC will collect, process, archive, and distribute PACE data. OCI will consist of a cross-track rotating telescope, thermal radiators, along with half-angle mirror and solar calibration mechanisms. OCI's tilt mechanism will help avoid sun glint and single science detector design will inhibit image striping. Its signal-to-noise ratios will rival or exceed previous ocean color instruments. OCI will have two-day global coverage at a 60-degree instrument view angle.

The Hyper-angular Rainbow Polarimeter 2 (HARP-2) is a wide-swath imaging polarimeter capable of characterizing atmospheric aerosols for the purposes of sensor atmospheric correction and atmospheric science. The Spectro-Polarimeter for Exploration (SPEXOne) provides atmospheric aerosol and cloud data at high temporal and spatial resolution.

PACE is a NASA Class C mission with a notional launch date in the 2024 timeframe and a minimum mission duration of three years. Nominal spacecraft altitude is 676.5 kilometers (420 miles) with an inclination of 98-degrees. PACE will launch on a Space-X Falcon 9.

ACHIEVEMENTS IN FY 2021

The PACE team continued to make good progress in FY 2021 despite capacity limits for much of the fiscal year due to COVID-19 restrictions. The project returned on-site full time in August 2021. The SPEXOne polarimeter pre-ship review and shipment occurred in March 2021. The integration and testing phase for the spacecraft began in early September 2021. The OCI instrument level integration and testing began in early September 2021. The project completed the flight structure build and the propulsion module build.

WORK IN PROGRESS IN FY 2022

The PACE team continues progress in FY 2022 with on-site work at GSFC, and all elements of the observatory are now in-flight build. NASA held a 3-day PACE science and applications team meeting in October 2021; this was the second of a series of meetings for the science community to collaborate in order to advance the science and applications of PACE. The project received delivery of the flight solar array panels in January 2022. Vendors delivered the OCI flight optics and loop heat pipes. The PACE team is planning the OCI pre-environmental review for April 2022 and the ground system end-to-end test number 1 by May 2022. The project plans to hold its mission systems integration review in September 2022.

PACE completed a replan for COVID-19 impacts in November 2021. COVID-19 restrictions directly impacted PACE operations and despite progress since CDR. The delays and residual inefficiencies associated with the gradual return to work, as well as technical challenges, resulted in the need for the

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	Development	Operations

replan. NASA assessed cost and schedule impacts through this replan and the updated estimates for the cost of completing the mission.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

PACE expects the delivery of flight solar arrays to integration and testing in October 2022. Planning for the observatory (fully built satellite) pre-ship review (PSR) is in late October 2023.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2023 PB Request
KDP-B	Jul 2017	Jul 2017
KDP-C	Aug 2019	Aug 2019
KDP-D	Aug 2021	Oct 2022
Launch (or equivalent)	Jan 2024	May 2024
End Prime Mission	Apr 2027	Aug 2027

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2020	558.0	>70%	2022	632.3	+13%	LRD	Jan 2024	May 2024	4

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**558.0**	**632.3**	**+74.3**
Aircraft/Spacecraft	103.6	132.0	+28.4
Payloads	79.2	168.7	+89.5
Systems I&T	18.8	27.2	+8.4
Launch Vehicle	105.0	80.4	-24.6
Ground Systems	19.3	28.9	+9.6
Science/Technology	50.0	56.9	+6.9
Other Direct Project Costs	182.1	138.2	-43.9

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Polarimeter (HARP-2) - Contribution	Measures how the oscillation of sunlight changes by passing through clouds, aerosols, and the ocean	Provider: University of Maryland Baltimore County (UMBC) Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): UMBC	N/A
Polarimeter (SPEXOne) - Contribution	Measures how the oscillation of sunlight changes by passing through clouds, aerosols, and the ocean.	Provider: Netherlands Institute for Space Research (SRON) Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): SRON	N/A
Ocean Color Instrument	Highly advanced optical spectrometer that will measure properties of light over portions of the electromagnetic spectrum	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Spacecraft	Provides a platform for instruments	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Launch Vehicle	Provides launch services for the PACE Observatory	Provider: SpaceX Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Mission Operations and Ground system	Provides software and system with capabilities for command and control, mission scheduling, long-term trending, and flight dynamics analysis. Collects, processes, archives, and distributes PACE data	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: The Main Optical Bench/Main Optical Sub-Bench (MOB/MOSB) parallel alignment activities are not successful, Then: Additional re-alignment would be necessary, resulting in a further MOB/MOSB schedule slip.	The OCI team is proceeding to install lenses with low risk due to the ability to look at the image position with the Ground Support Equipment detectors.
If: Current OCI gain stability and noise margin is not adequate, Then: OCI will exhibit decreased capability.	Engineers inserted interface tests into the test program to assess expected flight system performance.

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	Development	Operations

Acquisition Strategy

GSFC will build the spacecraft and OCI instrument in-house. UMBC will contribute the HARP-2 polarimeter. The Netherlands Institute for Space Research will contribute the SPEXOne polarimeter. The PACE Project worked with the NASA LSP to award the launch services contract to SpaceX in February 2020.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Launch Vehicle	SpaceX	Hawthorne, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Mar 2019	Preliminary Design Review (PDR)	Successful	Jan 2020
Performance	SRB	Jan 2020	Critical Design Review (CDR)	Successful	Aug 2022
Performance	SRB	Aug 2022	Systems Integration Review (SIR)	TBD	Sep 2023
Performance	SRB	Sep 2023	Operations Readiness Review (ORR)	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Sustained Climate Observations Future Mi	0.0	34.3	**38.0**	60.0	50.0	50.0	50.0
Earth Systematic Missions (ESM) Research	24.9	25.7	**29.8**	33.0	40.5	40.1	41.0
Ocean Surface Topography Science Team (O	5.8	5.9	**6.0**	6.2	6.2	6.3	6.5
Earth Observations Systems (EOS) Researc	10.7	10.7	**10.7**	10.7	10.7	11.0	11.0
Landsat 9	64.2	2.8	**2.9**	3.0	3.0	3.1	1.3
Sage III	4.6	4.6	**4.7**	4.8	4.8	4.8	4.8
Radiation Budget Instrument (RBI)	0.5	7.7	**0.0**	0.0	0.0	0.0	0.0
Sustainable Land Imaging	20.3	38.3	**106.8**	135.2	135.2	138.5	141.4
Earth from ISS	1.6	1.7	**1.7**	1.5	0.9	0.0	0.0
Total Solar Irradiance Sensor-2 (TSIS-2)	9.6	36.5	**54.1**	19.6	6.2	6.2	3.6
Earth Radiation Budget Science	17.2	14.8	**12.4**	15.8	15.9	16.9	17.0
Ozone Mapping and Profiler Suite (OMPS)	7.4	6.4	**3.7**	3.0	1.5	1.4	1.4
Total Solar Irradiance Sensor-1 (TSIS-1)	3.9	4.7	**4.8**	4.9	4.9	4.9	4.9
CLARREO Pathfinder	24.5	18.5	**23.4**	15.5	5.7	2.8	2.8
Earth System Observatory Future Missions	46.3	117.9	**211.5**	304.8	478.9	608.5	552.3
Earth Science Program Management	48.9	64.1	**53.0**	55.9	61.1	60.0	60.3
Precipitation Science Team	6.4	6.5	**6.6**	6.8	6.8	7.0	7.1
Ocean Winds Science Team	3.0	3.1	**3.2**	3.3	3.3	3.3	3.4
Land Cover Science Project Office	1.3	1.3	**1.4**	1.4	1.4	1.4	1.5
Ocean Salinity Science Team	7.5	7.6	**7.8**	8.0	8.0	8.2	8.4
Soil Moisture Active and Passive (SMAP)	12.9	6.5	**13.0**	13.4	13.8	13.7	14.0
Deep Space Climate Observatory	1.7	1.7	**1.7**	1.7	1.7	1.7	1.7
Global Precipitation Measurement (GPM)	21.2	24.4	**22.0**	25.6	23.1	23.3	23.2
Ocean Surface Topography Mission (OSTM)	0.5	0.0	**0.0**	0.0	0.0	0.0	0.0
Suomi National Polar-Orbiting Partnershi	3.7	3.8	**3.9**	4.0	4.0	0.0	0.0
Terra	29.2	22.8	**30.7**	9.0	9.0	0.0	0.0
Aqua	33.3	28.8	**30.7**	11.7	11.7	0.0	0.0
Aura	25.5	20.2	**20.5**	8.2	6.3	0.0	0.0
SORCE	0.2	0.0	**0.0**	0.0	0.0	0.0	0.0
ICESat-2	19.5	27.0	**22.9**	24.2	23.5	25.3	25.8
GRACE Follow-On	4.0	11.1	**11.2**	11.5	11.5	12.0	12.0
Total Budget	**460.4**	**559.4**	**739.0**	**802.7**	**949.5**	**1,050.3**	**995.3**
Change from FY 2022 Budget Request			**179.6**				
Percent change from FY 2022 Budget Request			**32.1%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

OTHER MISSIONS AND DATA ANALYSIS

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Earth Systematic Missions Other Missions and Data Analysis includes operating missions and their science teams and competed research projects. Mission science teams define the scientific requirements for their missions and generate algorithms used to process the data into useful data products. The research projects execute competitively selected investigations related to specific mission measurements.

Also included are Sustainable Land Imaging activities, as well as smaller missions in formulation and development, such as the Ozone Mapping and Profiler Suite Limb Sounder and Total and Spectral solar Irradiance Sensor-2.

Mission Planning and Other Projects

EARTH SYSTEMATIC MISSIONS (ESM) RESEARCH

ESM Research funds various science teams for the Earth Systematic missions. These science teams are composed of competitively selected individual investigators who analyze data from the missions to address related science questions.

Recent Achievements

Several published papers last year cited ICESat-2 to study sea ice properties, its thickness, and changes. A research team demonstrated, for the first time, that ICESat-2 can detect summer melt features on sea ice from a spaceborne altimeter system. They showed that ICESat-2 can provide precise measurements of sea ice surface roughness, pressure ridge height, and sea ice floe size distribution, resolving features as narrow as 7 meters and achieving a vertical height precision of 0.01 meter. A study used ICESat-2 photon data and coincident high-resolution satellite imagery from WorldView-2 and Sentinel-2 over different sea ice topographies to locate individual melt ponds on Arctic sea ice during the summer months. Sea ice melt ponds reduce both the reflective and insulative properties of sea ice, determining their locations on sea ice is a critical observation for accurately calculating sea ice height and sea ice freeboard, i.e., the thickness of sea ice protruding above the water level, using laser and radar altimeters.

Another study looked at high-resolution laser altimetry measurements made by ICESat-2Then they compared the results using near-synchronous data collected by ESA's CryoSat-2 radar altimeter as part of the CRYO2ICE orbit alignment campaign over the Arctic Ocean. The team found agreement in the along-track sea surface height anomalies between the two instruments, as well as in the gridded monthly sea surface height anomaly estimates.

Data collected over the Southern Ocean and Antarctic coastal areas made comparisons between measurements taken by ICESat-2 and CryoSat-2 over sea ice. Scientists offered the first examination of the ICESat-2 and CryoSat-2 sea ice freeboards, the snow depth derived from their differences, and the calculated sea ice thickness and volume. Their analysis spans an 8-month winter between April and November 2019 and characterized the behavior of the circumpolar ice cover in seven geographic sectors. They found that Antarctic snow depth estimates are highly correlated with ICESat-2 freeboards, with the ICESat-2 freeboard explaining > 90 percent of the variance in snow depth. Their results suggest that more than 60 –70 percent of the ICESat-2 freeboard is snow. At the sector scale, the adjusted estimates seem to

OTHER MISSIONS AND DATA ANALYSIS

be more credible than a continent-wide estimate, although better assessment of these parameters awaits better field measurements.

Members of the NISAR science team conducted a study of tropospheric models to use for algorithm improvements in the mission data processing. This approach seeks to mitigate the effects of atmospheric water vapor as a noise source in the geodetic time-series thereby increasing NISAR's ability to resolve and track land/ice surface movement. The team included community members around the world with interest in atmospheric modeling and quality analysis. The team considered several models, then selected five models for detailed evaluation. The criteria for selection were accuracy relative to Global Navigation Satellite System station estimates of path delay, resolution, latency, and availability. The team selected the European Center for Medium-range Weather Forecast model.

OCEAN SURFACE TOPOGRAPHY SCIENCE TEAM (OSTST)

OSTST uses scientific data from the Ocean Surface Topography Mission and Jason radar altimetry satellites. Together with data from international altimetry satellites such as ESA's Sentinel-3a, OSTST can measure global sea surface height. Data from tide gauges and a handful of calibration stations such as the Harvest oil platform help validate the satellite data.

Recent Achievements

A joint NASA/NOAA solicitation re-selected the OSTST in 2019 through a competitive process, which resulted in the largest team to date being selected for support by NASA. NASA investigators joined scientists supported by NOAA and CNES to form a new OST Science Team. The OSTST continues to produce and analyze high-precision records of sea surface height and satellite-derived ocean circulation. Recent results have shown how seasonal and decade-long variations in the ocean can combine with ongoing sea level rise to cause increases in high tide flooding. The results demonstrate how climate change impacts ocean circulation and ocean currents and how oceans continue to warm and expand, resulting in accelerated global mean sea level rise. Ocean altimetry records were also used to improve our understanding of sea level rise, including the ongoing acceleration in the rate of rise, and to explain changes in the ocean circulation in all the global oceans, including the Arctic. Many members of the OSTST are also assessing data from the Sentinel-6 Michael Freilich mission, which has been flying in close formation with Jason-3 for the purposes of cross-calibrating the satellites and preserving the integrity of the long-term climate record of sea level change. Assessments of the Sentinel-6 data show it to be of excellent quality and that it will easily meet its requirements for supporting oceanography, climate science, and ongoing monitoring of global sea level rise. Data from Sentinel-6 is being ingested and served entirely through cloud services, making it the first NASA product to provide all data services through the cloud. Although most access to date has been downloading data from the cloud, NASA anticipates that in-cloud use of the data will increase after publicly releasing all data from the mission after commissioning, which will end during FY 2022.

EARTH OBSERVATION SYSTEMS (EOS) RESEARCH

EOS Research funds science for the EOS missions, currently Terra, Aqua, Aura, and ICESat missions. The project competitively selects individual investigators to undertake research projects that analyze data from specific missions. Overall, most selected activities focus on science data analyses; however, some funded activities continue algorithm improvement and validation for the EOS mission instrument data products.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

Human activities such as livestock production and the creation and maintenance reservoirs for water storage also have significant impacts on the global carbon budget through the production and emission of methane. For example, a study integrated several geospatial (Shuttle Radar Topography Mission derived water body data) and remote sensing datasets (Moderate Resolution Imaging Spectroradiometer (MODIS), AMSER-E) along with field-based methane flux measurements into a modelling framework to estimate reservoirs-based methane emissions across the globe. They found that global reservoir area is 297 x 103 km2, with mean methane emissions of 10.1 Tg (1 Tg=1 million tons) per year, approximately equivalent to one third of annual methane emissions from biomass burning. The new datasets and methodologies derived in this study provide a novel framework to better understand and model the current and future role of reservoirs in the global methane budget.

Owing to practical limitations, especially at remote or heavily vegetated volcanoes, less than half of Earth's 1400 subaerial (existing in open air) volcanoes have ground monitoring. Researchers developed the first archive of both satellite and ground-based seismic, deformation, degassing, and thermal data to quantify the amount of detectable volcanic activity in the United States and its territories. This study found 96 volcanoes in the U.S. with some type of volcanic activity, with newly identified thermal activity at 30 volcanoes from analysis by the ASTER sensor. Researchers also used MISR, MODIS, and the Ozone Measuring Instrument (OMI) to classify and track volcanic emissions from Icelandic volcanoes based on content and ash particle size. They used these data to illustrate the potential to distinguish qualitative differences in eruptive magma composition based on particle light absorption and plume profile from remote sensing.

Scientists analyzed a 16-year record 2002-2018) of carbon oxide from Measurement of Pollution in the Troposphere and Aerosol Optical Dept from MODIS (both on the Terra satellite) and diagnosed the drivers of regional differences that could account for a slow-down in the declining carbon oxide trend. They found that carbon oxide declined faster in the first half (2002-2010) compared to the second half (2010-2018), while AOD was more variable. They attributed a large first-half decline of carbon oxide over Northeast China to improvement in combustion efficiency, and a smaller decline in the second half due to additional air quality improvements after 2010. The AOD records show that local changes in biomass burning are sufficiently strong to counteract the global downward trend in atmospheric carbon oxide, particularly in late summer.

SUSTAINABLE LAND IMAGING (SLI)

The SLI project enables the development of a multi-decade, space-borne system that will provide U.S. users with high quality global land-imaging measurements. These measurements will be compatible with the existing Landsat record and will address near and long-term issues of continuity risk. They will also evolve flexibly and responsibly through investment and introduction of new sensor and system technologies. Under the SLI framework, NASA will maintain responsibility for developing, launching, and initial checkout of space systems. The U.S. Geological Survey (USGS) will be responsible for collecting and documenting user needs, developing the associated ground systems, and operating the on-orbit spacecraft. USGS will also collect, calibrate, archive, process, and distribute SLI system data to users.

Through the implementation of SLI technology activities, NASA will enable new SLI measurement technologies, capabilities, and architectures. The Sustainable Land Imaging-Technology (SLI-T) program

OTHER MISSIONS AND DATA ANALYSIS

element aims to: demonstrate improved, innovative, full-instrument concepts for potential infusion into the architecture and design of the next generation of Landsat missions. SLI-T develops technologies at the component and/or breadboard-level that have long-term potential to improve future land imaging instruments and systems significantly through substantial architecture changes. NASA will solicit instrument and subsystem development activities in coordination with the Landsat science community.

SLI funding also supports the development of the next generation of Landsat observing system approaches, Landsat Next. To minimize the risk of gaps while taking advantage of cost savings and capability enhancements resulting from the technology development activity outlined above, the Administration will make key strategic decisions for Landsat Next in the upcoming FY 2024 budget process.

Additional SLI activities support efforts to minimize costs and maximize the overall utility for U.S. users by responsibly engaging with international partners to ensure access to high-quality data and fusion of those measurements with those from the U.S. Landsat missions. NASA and USGS conducted pre-launch cross-calibration investigations with the European developers of the Sentinel-2A/B land imaging system, ensuring uniform calibration of both Landsat 8 and Sentinel-2A/B instruments to the same standards. The USGS, supported by NASA and other agencies, is serving as the primary United States Government point of contact to ensure access to and archiving of Sentinel-2 data products for U.S. research and operational users.

Recent Achievements

Five SLI-T grants NASA awarded under a competitive solicitation in 2015 were completed and one grant continued to make substantial progress in FY 2021. The SLI architecture study team extensively referenced the results from these projects. Additionally, two projects performed additional aircraft demonstrations of new instruments in FY 2021, and analysis of the data from the test flights is ongoing, with some of the data already shared with NASA scientists.

Six new grants NASA awarded in July 2020 continued to make progress in FY 2021. The grants support technology development activities aimed specifically at demonstrating improved, innovative, full-instrument concepts for potential infusion into the design of missions beyond Landsat Next. Development and technical maturation at the component and/or breadboard-level have long-term potential to significantly improve future land imaging instruments and systems through substantial architecture changes. NASA funded one of the Earth Science and Technology Office (ESTO) Instrument Incubator Program (IIP) grants for a flight demonstration of an uncooled long wavelength infrared bolometer-based imager, with planned launch in FY 2022 as a hosted payload.

In 2021, Pre-Phase A activities for Landsat Next included the award of seven instrument studies to inform mission concept development. The studies explore the state of technology in visible to short wavelength infrared and thermal instruments for possible single satellite and constellation mission concepts.

CLARREO PATHFINDER (CPF)

CPF will measure sunlight reflected by the Earth and Moon and improve the accuracy of these measurements by five to ten times compared to current best sensors. Higher accuracy means greater certainty in the measurements, which will make it possible to detect Earth's subtle climate change trends decades sooner than otherwise possible.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

The project continues to work on flight hardware development. The International Space Station (ISS) has tentatively committed to manifest CPF on a future SpaceX launch and the project continues interface design and launch load analyses accordingly. ISS agreed to hold the designated external payload site on ISS free for CPF until 2030 to enable an extended mission.

TOTAL SOLAR IRRADIANCE SENSOR-2 (TSIS-2)

The TSIS-2 instrument will maintain and extend the 41-year measurement record of total solar irradiance and spectral solar irradiance beyond 2023 provided by TSIS-1 and earlier missions. Researchers have used the solar irradiance data to understand how the solar energy affects the Earth system over an 11-year cycle and longer time scale. NASA is implementing TSIS-2 by leveraging the available spare parts from the TSIS-1 mission to the greatest degree possible. NASA will implement TSIS-2 as a Class D payload and as a free flyer. The mission will operate for no less than three years. Formulation began in FY 2019.

Recent Achievements

In FY 2021, the spacecraft developer presented a preliminary design of the spacecraft to reviewers and began work on the more detailed design. The instrument vendor has completed approximately 85 percent of the development of one instrument and 50 percent of the second instrument.

EARTH RADIATION BUDGET SCIENCE (ERBS)

The ERBS project produces climate data records of Earth's radiation budget and the associated cloud, aerosol, and surface properties. The project utilizes data from the multiple radiation budget instruments in orbit and ancillary measurements to produce integrated, self-consistent data products over the entire suite of radiation budget instruments. The data products utilize coincident imager measurements and Clouds and the Earth's Radiant Energy System (CERES) instrument broadband radiative fluxes from Terra, Aqua, Suomi National Polar-orbiting Partnership, NOAA-20, and operational geostationary satellite observations. In total, scientists have used 30 instruments on 24 spacecraft thus far to produce an accurate and temporally consistent description of the radiation budget, not only at the top of the atmosphere but also at the surface and within the atmosphere. The ERBS project is the only project worldwide whose prime objective is to produce global, climate-quality ERB data from dedicated ERB satellite instruments.

Recent Achievements

In FY 2021, the scientific community used CERES data products to publish peer-reviewed scientific papers on research in the following areas: earth's energy imbalance, climate feedback, aerosol radiative forcing, atmospheric and oceanic energy transports, polar climate, and climate model evaluation. In addition, CERES near-real time global flux data products helped to support monitoring of ground-based solar panel operations and crop modeling. The ERBS team generated data products from all six CERES instruments and continued to perform inter-comparison campaigns between the Terra, Aqua, Suomi-NPP and NOAA-20 instruments. The ERBS operations team placed the CERES S-NPP/FM5 instrument in a normal biaxial scan mode to collect data needed to improve higher-level data products. To ensure continuity of CERES cloud and radiation data products across different satellites, the ERBS team ingested VIIRS-CrIS fusion IR radiance data into CERES Clouds processing stream, providing a consistent set of spectral bands for all satellites. The ERBS team also completed building a processing framework for the

OTHER MISSIONS AND DATA ANALYSIS

CERES Clouds retrieval subsystem with an automation capability that can process imager data on Terra, Aqua, Suomi-NPP and NOAA-20 using a consistent set of computer programs. The team also fully automated processing of a key CERES climate data product, Energy Balanced and Filled, which enables monthly updates with reduced latency.

OZONE MAPPING AND PROFILER SUITE LIMB SOUNDER (OMPS-L)

The advanced Ozone Mapping and Profiler Suite (OMPS) tracks the health of the ozone layer and measures the concentration of ozone in the Earth's atmosphere. OMPS is a three-part instrument, a nadir mapper that maps global ozone with about 50-km ground-resolution, a nadir profiler that will measure the vertical distribution of ozone in the stratosphere, a limb profiler that will measure ozone in the lower stratosphere, and troposphere with high vertical resolution. The entire OMPS suite currently operates on the Suomi NPP spacecraft. To ensure data continuity, a copy of this suite will fly on NOAA's Joint Polar Satellite System-2 (JPSS-2) mission, planned for launch in FY 2023. NASA is responsible for providing the OMPS-Limb profiler for integration on the OMPS instrument. The project budget also supports OMPS-Limb profilers for JPSS-3 and JPSS-4.

Recent Achievements

In FY 2021, the OMPS team successfully delivered the JPSS-3 Limb to the integrated sensor suite. Additionally, the team provided technical support for OMPS during JPSS-2 spacecraft testing, completed the JPSS-4 Limb sensor build, and started instrument-level testing.

EARTH SYSTEM OBSERVATORY FUTURE MISSIONS

In January 2018, the National Academies released a new Earth Science Decadal Survey, entitled "Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space." In addition to recommending that NASA complete the missions that were already in formulation and development, this Decadal Survey recommended an observing program that prioritized observables to address key science and applications objectives for the coming decade. These include the following high priority "designated observables" (DOs): Aerosols; Clouds, Convection, and Precipitation; Mass Change; Surface Biology and Geology; and Surface Deformation and Change. In addition to the DOs, the Decadal Survey called for a new, competed program element, termed "Earth System Explorers," to address other "targeted observables."

In October 2018, NASA initiated studies to develop concepts for missions/observing systems to address the five DO priorities. These missions/observing systems will constitute a new Earth System Observatory (ESO) and be implemented as cost-constrained projects.

Recent Achievements

In FY 2021, ESD initiated the pre-formulation phase for four DO missions addressing: Aerosols; Clouds, Convection, and Precipitation; Mass Change; Surface Biology and Geology. The fifth, targeting Surface Deformation and Change, will remain in the study phase to incorporate lessons learned from the related NASA-ISRO Synthetic Aperture Radar (NISAR) mission. The four ESO missions will complete their mission concept reviews in FY 2022. The Mass Change and Surface Biology and Geology missions will target launch in FY 2028. NASA will implement two missions to address Aerosols and Clouds, Convection and Precipitation, with the first scheduled to launch to an inclined orbit in FY 2028 and the second to launch into a polar orbit in FY 2030.

OTHER MISSIONS AND DATA ANALYSIS

SUSTAINED CLIMATE OBSERVATIONS FUTURE MISSIONS

Sustained climate observations provide ongoing records of the changing climate and Earth system that support climate change prediction and implementations of adaptation and mitigation measures. NASA will work with international and commercial stakeholders to identify opportunities for achieving these observations through effective and cost-efficient collaborations.

Recent Achievements

In FY 2021, NASA supported two studies for potential instrument contributions to European Space Agency (ESA) missions. In the first, they examined enhancements to the Sentinel-6 radiometer as part of ESA's Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL) mission, which would extend the record of land and sea ice elevation established by the ESA CryoSat-2 and complement NASA's ongoing ICESat-2 mission. In the second study, they examined augmenting the L-band radiometer on ESA's Copernicus Imaging Microwave Radiometer (CIMR) mission with a wideband spectrometer, which would build on NASA's Aquarius and SMAP missions, as well as ESA's SMOS mission. This significantly improves retrievals of ocean salinity, soil moisture and sea ice thickness. The team will complete the studies in FY 2022. If, after reviewing the study outcomes, NASA decides to commit to providing these contributions, each study would transition to formulation.

EARTH SCIENCE PROGRAM MANAGEMENT

The Earth Science Program Management budget supports critical flight project management functions executed by the ESM program offices at NASA Goddard Space Flight Center (GSFC) and the Jet Propulsion Laboratory (JPL), and the Earth System Science Pathfinder Program Office at NASA Langley Research Center (LaRC). This budget supports:

- The GSFC conjunction assessment risk analysis function, which determines maneuvers required to avoid potential collisions between spacecraft and to avoid debris;
- The technical and management support for the international Committee on Earth Observation Satellites, which coordinates civil space-borne observations of Earth. Participating agencies strive to enhance international coordination and data exchange and to optimize societal benefit;
- Senior Review Board teams, who conduct independent reviews of the various flight projects in Earth Science; and
- Earth Science division communications and public engagement activities.

PRECIPITATION SCIENCE TEAM

The Precipitation Science Team carries out investigations of precipitation using measurements from, but not limited to, the Tropical Rainfall Measuring Mission (TRMM) mission, which ended in 2015, the Global Precipitation Measurement (GPM) mission, which launched in February 2014, and GPM mission constellation partner spacecraft. GPM mission constellation partners include NOAA, Department of Defense, Centre National d'Études Spatiales (CNES), Japan Aerospace Exploration Agency (JAXA), and Exploitation of Meteorological Satellites (EUMETSAT). This program supports scientific investigations in three research categories:

- Development, evaluation, and validation of TRMM and GPM retrieval algorithms;
- Development of methodologies for improved application of satellite measurements; and

OTHER MISSIONS AND DATA ANALYSIS

- Use of satellite and ground measurements for physical process studies to gain a better understanding of the global water cycle, climate, and weather and concomitant improvements in numerical models on cloud resolving to climate scales.

Recent Achievements

Team members continued to use airborne and ground-based observations from GPM, related field campaigns, and long-term fixed ground sites to develop advanced algorithms in cold-season precipitation over steep mountains and for warm-season convective storms. Several studies summarized validation efforts for GPM, including use of the GPM validation network over the United States to examine rain drop size estimates, evaluation of the GPM merged multi-satellite rainfall product over South Korea and over several Pacific Ocean atolls, and assessment of vertical profiles of condensed water from the GPM microwave imager (GMI). A number of studies used GPM data to characterize precipitation regionally and globally. The studies included monsoon precipitation in the Peruvian Andes Mountains, deep thunderstorm events in the Mediterranean, lake-effect snowfall in the Great Lakes region, and the diurnal variation of precipitation and the distribution of rain drop sizes globally. Several studies described advances in precipitation retrieval algorithms, including incorporation of information on changing characteristics of the land surface caused by rainfall, issues with measuring snowfall over snow covered surfaces, special issues tied to measurements in high latitude regions, and identification of hailstorms from space. Furthermore, researchers made advances in the use of artificial intelligence, or machine learning, for retrieving snowfall, precipitation over mountains, and precipitation. While GPM precipitation measurements have advanced science, the data have also supported important applications, including landslide forecasting, natural disaster monitoring, and ingestion of GPM constellation measurements into numerical weather prediction models.

OCEAN WINDS SCIENCE TEAM

The Ocean Winds Science Team (OWST) uses scientific data received from the QuikSCAT satellite, RapidScat instrument, and other international missions, which measure ocean surface winds by sensing ripples caused by winds at the ocean's surface. From this data, scientists can compute wind speed and direction thus acquiring global observations of surface wind velocity each day. Wind data from ships and buoys serve to calibrate the satellite data.

Recent Achievements

Preparations for the upcoming launch of Compact Ocean Wind Vector Radiometer (COWVR) instrument were underway this year. The COWVR instrument will launch to the ISS later this winter and will provide coincident observations with the Department of Defense STP-H8 mission. OWST members are actively participating in the ongoing NASA EVS-3 S-MODE mission that collects simultaneous wind and currents measurements from a NASA airborne platform to characterize air-sea interactions at small spatial scales. The OWST continued to examine new mechanisms of air-sea interaction that enabled improved forecasting of tropical hurricanes and cyclones. Recent improvements in ocean, wind, and climate data records, including better handling of rain contamination (the degraded ability of the passive microwave sensors to measure ocean wind during rain events), and facilitated applications in near-coastal regions and enabled better intercalibration studies. OWST also explored conceptually novel approaches to measure winds from space in preparation for the upcoming NASA Earth Explorer mission opportunity recommended by the National Academies of Sciences.

OTHER MISSIONS AND DATA ANALYSIS

LAND COVER PROJECT SCIENCE OFFICE (LCPSO)

The LCPSO maintains over 40 years of calibration records for the Landsat 1 through Landsat 8 series of satellites. The office also provides community software tools to make it easier for users to work with this data. In collaboration with USGS, LCPSO supports cross-calibration of the Landsat record with other international sensors, provision of preprocessed data sets for land-cover change analysis and facilitates use of international data sets for improved land cover monitoring.

Recent Achievements

This year, the LCPSO continued science support for the Harmonized Landsat Sentinel-2 (HLS) product, which the Land Processes Active Archive Center is now distributing. This product combines observations from the U.S. Landsat and European Union Sentinel-2 satellite series into a single data set, fulfilling a priority of the 2016 interagency U.S. Group on Earth Observations Satellite Needs Working Group (SNWG) survey process. HLS data support additional SNWG products, including surface water extent and near real-time forest disturbance mapping. The LCPSO also fielded an online archive of land-cover data products previously funded by the NASA Land-Cover/Land-Use Change Program. This archive allows open access to principal investigator-generated map products that were previously not easily accessible by researchers or the public.

OCEAN SALINITY SCIENCE TEAM (OSST)

The OSST supports the development and construction of surface salinity products from L-Band microwave radiometers such as Aquarius, SMAP, and data sets of opportunity such as ESA’s Soil Moisture and Ocean Salinity (SMOS) mission. The team also seeks to understand upper-ocean processes that impact variability of surface salinity in order to improve interpretation of the space-based salinity products. The team is working on a SMAP salinity product that is consistent with the Aquarius salinity product, which ended in June 2015.

Recent Achievements

Recent release of the ocean salinity maps produced by OSST from NASA SMAP mission data demonstrated its improved accuracy and coverage, approaching the quality of the Aquarius satellite salinity measurements. The improvements allowed OSST to gain new insights about ocean physical and biochemical processes, climate variability, water cycle, and extreme weather events. OSST also delivered NASA multi-mission satellite salinity product combining measurements from Aquarius and SMAP. The new product marks the first continuous and consistent NASA climate satellite salinity record. The product allows a first glimpse into climate and decadal changes in ocean salinity structure that the OSST plans to explore for a few years. The OSST actively collaborated with ESA scientists to develop a joint NASA/ESA satellite salinity evaluation platform. The NASA-ESA Joint Program Planning Group endorsed this effort that paves the way for future NASA/ESA collaboration including development of the requirements for the upcoming CIMR mission. Finally, NASA selected a new salinity airborne/satellite/in situ mission via a competitive process. The new salinity mission, Salinity and Stratification at the Sea Ice Edge, will explore the potential of salinity in predicting sea ice dynamics in the coming years.

OTHER MISSIONS AND DATA ANALYSIS

Operating Missions

ICE, CLOUD, AND LAND ELEVATION SATELLITE (ICESAT-2)

The ICESat-2 mission measures global elevation to provide an important multi-year record needed to determine sea ice thickness and ice sheet mass change. It also provides topography and vegetation data around the globe. These additional data products support estimates of biomass and carbon in aboveground vegetation in conjunction with related missions, measurements of ocean topography, inland water body elevation such as lakes and rivers, and cloud properties. The ICESat-2 observatory has one instrument, the Advanced Topographic Laser Altimeter System (ATLAS), which measures the round-trip time of laser light from the observatory to Earth and back as the basis for the mission's elevation measurements. Launched on September 15, 2018, ICESat-2 will remain in prime mission operations through December 2021 and then will enter its extended mission operations phase.

Recent Achievements

The ICESat-2 observatory and ATLAS instrument continue to operate nominally. To date, over 3,900 users have downloaded over 17 million data files. The initial science results from ICESat-2 have demonstrated that the elevation data is accurate to less than 3 centimeters vertically, the location is known to less than 4 meters horizontally, and that measurements from ICESat-2 are of comparable quality to measurements from low-flying aircraft. The data show the ongoing ice loss from the Greenland and Antarctic ice sheets, and that the ice shelves of Antarctica may be losing more ice than previously thought. In addition, analysis has shown that the green laser light of ICESat-2 can penetrate up to 15 meters (nearly 50 feet) of water, enabling shallow water bathymetry measurements from space. To date, more than 100 peer-reviewed publications in the scientific literature have used ICESat-2 data. As the ICESat-2 data volume continues to grow, the ICESat-2 project has developed tools for cloud-based data access and analysis.

GRACE FOLLOW-ON

The Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) mission provides continuity of month-to-month mass change observations and high-resolution global models of Earth's gravity field, as in the original GRACE mission (launched in 2002). The GRACE-FO mission allows scientists to gain new insights into the dynamic processes of Earth's water cycle, including variations in water storage over land, the mass of glaciers and ice sheets, and sea level and ocean currents. GRACE-FO also maps large earthquakes and tectonic processes. Data from the mission, in combination with other existing sources of data, greatly improves scientific understanding of how Earth's water cycle evolves. GRACE-FO data is vital to ensuring there is a minimal gap in mass change measurements following the decommissioning of the original GRACE mission in 2017. GRACE-FO is a partnership with the German Research Centre for Geosciences (GFZ). Launched on May 22, 2018, GRACE-FO will remain in prime mission operations through November 2023.

Recent Achievements

As of October 2021, the mission added 37 monthly Global Mass Change datasets to the more than 15 years of monthly mass change maps archived by GRACE. The combined data record now consists of 200

OTHER MISSIONS AND DATA ANALYSIS

monthly global mass change maps, spanning nearly two decades. The GRACE-FO science data system team has delivered these data to NASA's Physical Oceanography Distributed Active Archive Center ahead of schedule (on average 39 days vs the 60-day requirement), enabling scientists and resource managers worldwide to provide timely analysis of weather and climate-related events. This has also led to accurately and efficiently monitoring the long-term changes in Earth's ice sheets and glaciers, underground water storage, and crustal deformation due to major earthquakes. The GRACE-FO team is producing a near real-time data stream with a latency of approximately three days to aid in the management of drought and water resources in the United States. In addition to the mass change observations, GRACE-FO also delivers approximately 500 daily near real time profile of atmospheric temperature and humidity (via GPS radio occultation measurements). Operational weather forecast models ingest these data to improve the accuracy of predictions.

SOIL MOISTURE ACTIVE AND PASSIVE (SMAP)

The SMAP mission, launched in January 2015, provides a capability for global mapping of soil moisture with unprecedented accuracy, resolution, and coverage. The SMAP measurement system consists of a radiometer (passive) instrument and a synthetic aperture radar (active) instrument operating with multiple polarizations in the L-band range. Although the active radar instrument failed in July 2015, the radiometer is operating nominally, and continues to provide global mapping of soil moisture with accuracy, resolution, and coverage that exceeds the capability of other on-orbit systems. The SMAP project team has developed a blended data product that combines SMAP radiometer measurements with the European Copernicus Program’s Sentinel-1 active radar measurements. This operational product provides soil moisture information with higher spatial resolution whenever the two systems have coincident measurements.

SMAP is currently in extended operations.

Recent Achievements

In FY 2021, SMAP made significant improvements to its soil moisture and vegetation water content products obtained from a dual-channel algorithm. U.S. Federal agencies continue to increase their use of SMAP soil moisture data to meet or improve operational requirements. The U.S. Air Force's 557th Weather Wing has been using SMAP soil moisture data since November 2019. Similarly, the U.S. Navy’s Fleet Numerical Meteorology and Oceanography Center, National Oceanic and Atmospheric Administration (NOAA), and Environmental Modeling Center (NMC) are currently assessing the value of SMAP data to support operational needs, such as weather forecasts and ship navigation. In 2021, researchers at NASA and the United States Department of Agriculture (USDA) and National Agriculture Statistics Service (NASS) jointly developed the app, Crop Condition and Soil Moisture Analytics (Crop-CASMA), which can provide access to high-resolution data from the SMAP mission. Some of Crop-CASMA’s primary users will be USDA and NASS statisticians, who release weekly crop progress reports that currently classify states into moisture categories (very short, short, adequate, surplus) to aid farmers and farm managers. The reports also track crops’ health and growing progress. Crop-CASMA can help identify unplantable areas because of wet, saturated, frozen, excessively dry, or inaccessible fields. Maps showing the changes in soil moisture are made available to the multi-agency National Drought Mitigation Center (NDMC) which forms the weekly Drought Monitor by combining information on persistent soil water storage deficit.

OTHER MISSIONS AND DATA ANALYSIS

GLOBAL PRECIPITATION MEASUREMENT (GPM)

The GPM mission, launched in February 2014, advances the measurement of global precipitation through the combined use of active and passive remote-sensing techniques. Tracking storms as they move within the tropics and higher latitudes, GPM provides a three-dimensional view of their structural and microphysical properties and provides estimates of storm rainfall accumulations for major storm events. The GPM Microwave Imager (GMI) measures energy from different types of precipitation within clouds to estimate heavy to light rain and to detect falling snow. The Dual-frequency Precipitation Radar (DPR) provides three-dimensional information about precipitation particles, including their size distributions and associated rainfall rates, derived from reflected energy at two radar wavelengths at different heights within the cloud system. GPM is a joint mission with JAXA.

GPM is currently in extended operations.

Recent Achievements

GPM continued satellite operations, data processing and delivery, and science activities utilizing a full telework model to cope with restrictions imposed in response to the COVID-19 pandemic. The project continued to work with industry and the ISS to coordinate close approaches between GPM and other spacecraft. Continued development of a new control algorithm to be used in the event of multiple reaction wheel failures and completed upgrades to a back-up Mission Operations Center. This will add automation and allow for more efficient testing of ground system components without the need of 24x7 staffed operations. GPM scientists updated algorithms for rainfall retrievals from its multiple instruments and for combining data from other constellation satellites into a merged precipitation product known as Integrated Multi-satellite Retrievals for GPM (IMERG). The project led a three-session training event on IMERG products for the International Precipitation Working Group (IPWG), the premier international assembly of precipitation specialists, and increasing the visibility of GPM data and enhancing capacity building. The precipitation processing system (PPS) generated initial precipitation retrievals from DPR, whose scan pattern changed in May 2018, allowing for more accurate rainfall estimates. Within PPS, even under COVID-19 restrictions, there was an update to the operating systems of all production machines to bring them in line with current information technology security requirements, all while ensuring no impacts to real-time data production and latency. The GPM ground validation group continued its preparation for participation in upcoming synergistic field campaigns related to East Coast snowstorms and thunderstorm systems in Texas. The GPM Applications team focused on engaging new user communities and reaching out more extensively to other groups, developed new Applications Packages focusing on usage of GPM data for ecological monitoring and climate modeling, and ran a virtual workshop to engage the Transportation and Logistics communities.

SUOMI NATIONAL POLAR-ORBITING PARTNERSHIP (SUOMI NPP)

The Suomi NPP mission is a partnership between NASA and NOAA that was launched in October 2011. The five instruments on Suomi NPP provide visible and infrared multi-spectral global imagery, atmospheric temperature and moisture profiles, total ozone and stratospheric ozone profiles, and measurements of Earth's radiation balance. In addition to a wide range of applications studies, the NASA science focus areas served by Suomi NPP include atmospheric composition, climate variability and change, carbon cycle, ecosystems, water and energy cycles, and weather. Several primary Suomi-NPP products have demonstrated their capabilities to provide critical continuity and near-real-time data, extending the EOS observation long time-series in monitoring changes in land, ocean, and atmosphere as

OTHER MISSIONS AND DATA ANALYSIS

well as Earth's radiation budget. NASA built and launched Suomi NPP. NOAA operates the spacecraft and instruments. NASA and NOAA continue to collaborate to ensure meeting the shared objectives of both agencies.

Suomi NPP is currently in extended operations.

Recent Achievements

In FY 2021, the NASA Suomi NPP team continued to add to the existing data records from Earth Observing System missions, enabling scientists to build multi-satellite, multidecadal (greater than 30 years) time series with high accuracy and long-term stability suitable for studies of Earth systems science. For example, using high resolution active fire-detection products from Visible Infrared Imaging Radiometer Suite (VIIRS), scientists found that fires across boreal forests in Alaska, continental United States, and the Northwest Territories, Canada, are exhibiting overwintering. This behavior causes fires to smolder through the non-fire season and flare up in the subsequent spring. These conditions have become more frequent with climate change. In addition, total and vertical ozone measurements derived from Ozone Mapping and Profiler Suite (OMPS) show that the 2021 Antarctic ozone hole is larger and deeper than average, ranking the 13th largest in 43 years of satellite observations. Persistently cold temperatures and strong circumpolar winds in the Antarctic lower stratosphere drove the 2021 ozone depletion event.

To help monitor the impacts of the ongoing global pandemic in 2021, Suomi NPP products continued to contribute to the key socio-economic indicators in the tri-agency (ESA/NASA/JAXA) COVID-19 dashboard. For example, VIIRS aerosol, OMPS Sulfur Dioxide (SO_2) and Nitrogen Dioxide (NO2) products helped assess the impact of COVID-19 on air pollution. Cross-track Infrared Sounder (CrIS) measurements of tropospheric ozone also aided in evaluating model simulations of global tropospheric ozone responses to reduced NO_x emissions linked to the COVID-19 worldwide lockdowns. In addition, the VIIRS datasets continued to provide timely information during disaster events such as wildfires from California as well as other western states. OMPS SO_2 and aerosol index as well as CrIS SO_2 products also played an important role in early detection and tracking of the volcanic plumes during various volcanic eruptions in 2021.

TERRA

Terra, launched in December 1999, is one of the Earth Observing System (EOS) flagship missions. It enables a wide range of interdisciplinary studies of atmospheric composition, carbon cycle, ecosystems, biogeochemistry, climate variability and change, water and energy cycles, and weather. The Terra mission has provided more than 20 years of continuous data collection, including fundamental observations of the Earth's climate system, high-impact events, and adding value to other satellite missions and field campaigns. The spacecraft platform and five sensors are all fully functional, with the exception of the shortwave infrared bands in the Advanced Space-borne Thermal Emission and Reflection Radiometer instrument. Terra is a joint mission with Japan and Canada.

Terra is currently in extended operations.

Recent Achievements

In FY 2021, the Terra mission entered its 22nd year of operations. Terra, with its healthy suite of instrument and spacecraft systems, careful stewardship of spacecraft resources (fuel, batteries, data storage), and maintenance of instrument calibrations throughout the mission, continued to provide a unique, long-term climate and environmental record not available from any other satellite platform.

OTHER MISSIONS AND DATA ANALYSIS

Data from Terra instruments combined with other mission data showed that the imbalance between the energy emitted by Earth and the solar energy absorbed approximately doubled during the 14-year period from 2005 to 2019. Multiple Federal and international Agencies used Terra's land and atmospheric products for volcanic ash monitoring, weather forecasting, forest fire monitoring, carbon management, and global crop assessment. The mission's long-term record continued to be crucial in assessing the impacts to air quality during the initial COVID-19 lockdowns and subsequent increases in transportation and industrial activities both in the United States and globally. Together, Terra's five instruments continued to play a key role in understanding fire location and intensity, burn areas and revegetation, and injection and transport of aerosols, and carbon monoxide in the atmosphere These are especially important for the unprecedented 2021 wildfires in the United States. Direct broadcast and near-real-time data products from Terra sensors were especially critical for predictions of local air quality and smoke transport as well as fire management.

AQUA

Aqua, launched in May 2002, is one of the EOS flagship missions. Aqua improves our understanding of Earth's water cycle and the intricacies of the climate system by monitoring atmospheric, land, ocean, and ice variables. It was the first satellite launched into what has become the afternoon constellation of satellites, known as the A-Train, and remains the anchor satellite of that constellation. Four of Aqua's Earth observing instruments – the Atmospheric Infrared Sounder (AIRS), the Advanced Microwave Sounding Unit, Clouds and the Earth's Radiant Energy System (CERES), and the Moderate Resolution Imaging Spectroradiometer (MODIS) – continue to collect valuable data about the Earth's atmosphere, oceans, land, ice, and overall energy budget. The science community widely uses these data and in practical applications ranging from improved weather forecasting to monitoring forest fires, crop yields, volcanic ash plumes, and ice-infested waters. Aqua is a joint mission with Japan and Brazil.

Aqua is currently in extended operations.

Recent Achievements

In FY 2021, researchers published hundreds of peer-reviewed articles incorporating Aqua data, including articles that (1) provide long-term records of trace gases affecting air quality and climate, using AIRS data, (2) quantify the substantial increase since 2000 in the global population exposed to floods, using MODIS data, and (3) test how well state-of-the-art climate models represent observed changes in the Earth's radiation budget, using CERES data. A NASA-NOAA study incorporating Aqua CERES measurements of the Earth's energy budget determined that the rate of heat uptake by the Earth doubled between 2005 and 2019. The implications of the increase in planetary heating include global mean surface temperature rise, increased ocean warming, sea level rise, and intensification of the hydrological cycle. Researchers used AIRS data to evaluate the performance of climate models included in the latest Climate Model Intercomparison Project (CMIP6) and are a foundation for the 2021 Intergovernmental Panel on Climate Change (IPCC) Assessment Report (AR6), which cites AIRS data and several AIRS studies numerous times. Among the crucial datasets cited are AIRS measurements of trends in ammonia, a gas that leads to formation of aerosols harmful to human health. A 2021 study shows that the AIRS instrument is capable of monitoring regional variations in concentrations of chlorofluorocarbon-11 (CFC-11), a gas involved in the destruction of the ozone layer.

Throughout FY 2021, Aqua data and imagery monitored major environmental events around the world, from Hurricane Delta as it approached the U.S. Gulf Coast in early October 2020 to the volcanic

OTHER MISSIONS AND DATA ANALYSIS

emissions from the eruption of Cumbre Vieja on the Canary Island of La Palma in September 2021. Aqua monitored widespread fires in Bolivia in October 2020, the eruption of La Soufriere on the Caribbean Island of Saint Vincent starting in December 2020 and continuing through much of 2021, a winter dust storm blanketing much of northern China, spring drought conditions in the western United States and over 85 percent of Mexico, devastating summer fires in the western United States. Aqua imagery also captured unusually extensive summer melting in central Greenland, August fires in the western Amazon and southwestern Botswana, and September sea ice conditions affecting shipping in the Arctic's Northwest Passage in FY 2021.

AURA

Aura, launched in July 2004, is one of the EOS flagship missions. Aura advances the understanding of changes in the Earth's radiation balance, air quality, and the ozone layer that result from changes in atmospheric composition, climate variability, and weather by measuring atmospheric chemical composition, tropospheric/stratospheric exchange of energy and chemicals, chemistry-climate interactions, and air quality. Aura is also part of the A-Train. Two of Aura's four instruments are operational: the Microwave Limb Sounder and the Ozone Monitoring Instrument (OMI). Additional measurements include clouds, aerosols, solar spectral irradiance, and water vapor. Aura is a joint mission with the Netherlands, Finland, and the United Kingdom.

Aura is currently in extended operations.

Recent Achievements

More than 17 years into its mission, Aura continued to provide data for scientific research and societal benefit in FY 2021. OMI observed the unprecedented decrease in air pollution around the world associated with efforts to control the spread of COVID-19 in FY 2020. OMI measurements of nitrogen dioxide, a pollutant released during the combustion of fossil fuels, showed about a 30-40 percent decrease in many world cities during the height of the lockdowns in FY 2020 and a gradual recovery in pollutant emissions in late FY 2020 into FY 2021. Given that fossil fuels drive most world economies, OMI data assessed the impact of the pandemic on economic activity around the world, including in countries without reliable economic data. Air quality and health researchers also used the nitrogen dioxide data as a proxy of the effectiveness of lockdown efforts to contain or slow the pandemic in a given area. Climate scientists used the nitrogen dioxide measurements as a proxy for co-emitted carbon dioxide, a potent greenhouse gas. Scientific studies continue to use observations from Microwave Limb Sounder (MLS) in a wide range of scientific studies. Most notably, they have been central to further discoveries concerning the impacts on the stratosphere of the catastrophic Australian bush fires at the turn of 2019/2020. MLS and other observations had already shown that multiple thunderstorms triggered by the fires injected distinct plumes of highly polluted air into the stratosphere, where they remained coherent for several months, rising to as high as 30 km altitude. Further examination of MLS observations has revealed that the subsequent dispersal of the smoke particles from these plumes throughout the southern mid-latitude lower stratosphere provoked a conversion of chlorine (largely originating from chlorofluorocarbons and other industrial chemicals) from benign forms into those that destroy stratospheric ozone. Such conversion is already well known to occur on the surfaces of cloud particles in the polar regions, giving rise to the Antarctic "ozone hole" each austral spring. Similar reactions are also known to take place on other types of particles, including those resulting from volcanic eruptions. However, none of the volcanic or other forest fire events in the 17-year MLS record to date have resulted in robustly detectable conversion of stratospheric chlorine into ozone-destroying forms on a hemisphere-wide scale.

OTHER MISSIONS AND DATA ANALYSIS

Nevertheless, the degree of chlorine conversion was smaller than that in typical polar winters, and consistent with that, no observation of significant change in ozone occurred.

STRATOSPHERIC AEROSOL AND GAS EXPERIMENT III (SAGE-III)

SAGE-III, launched in February 2017, operates on the ISS, and provides global, long-term measurements of key components of Earth's atmosphere. The most important of these are the vertical distribution of aerosols and ozone from the upper troposphere through the stratosphere. In addition, SAGE-III provides unique measurements of temperature in the stratosphere and mesosphere and profiles of trace gases, such as water vapor and nitrogen dioxide, which play significant roles in atmospheric radiative and chemical processes. These measurements are vital inputs to the global scientific community for improved understanding of climate and human-induced ozone trends.

SAGE-III completed its prime mission in July 2020 and is now in extended operations.

Recent Achievements

The SAGE-III project continued to demonstrate improvements in operational efficiency for payload commanding and science data collection. As a result of these improvements, COVID-19 protocols implemented to reduce health-risks to the payload operators did not impact science data collection. Using an improved algorithm, the SAGE-III mission released a new version of the publicly available science data products. Of note is the new water vapor product with greater stability and accuracy. The new data products show the continued global decline in stratospheric aerosol injected by a moderate volcanic eruption (Raikoke 2019) and extreme Australian bushfires (early 2020).

The time evolution of the stratospheric aerosol is important in understanding what natural occurrences might have offset expected greenhouse gas induced temperature changes. The project continued to communicate with the international science community on the variations of stratospheric aerosol and ozone captured in the SAGE-III data products freely released to the public on a monthly schedule. The mission also released in a major NASA archive engineering data from a payload sub-system, the Contamination Monitoring Package (CMP), that records the external contamination environment at the location of SAGE-III payload on the ISS over the past 4-years. This data will be helpful to teams proposing new experiments hosted externally on the ISS.

EARTH FROM ISS

NASA's ISS program sponsored the development of several earth science instruments for the ISS. The Earth from ISS project ensures the appropriate processing of data and its availability to the earth science research community from the data collected by these instruments. This project invests in algorithm development, data production and distribution, as well as data analysis and modeling for the currently planned ISS earth science payloads.

The ISS Lightning Imaging Sensor (LIS) makes space-based global lightning observations, using the backup flight spare for the instrument that operated for 17 years on the Tropical Rainfall Measuring Mission. LIS provides a great opportunity to not only extend the TRMM record of tropical lightning measurements, but also to expand coverage to the higher latitudes missed by the previous mission. LIS observations continue to support the global scientific research community, across a wide range of disciplines that include weather and extreme storms, climate studies, atmospheric chemistry, and

OTHER MISSIONS AND DATA ANALYSIS

lightning physics. Researchers use LIS to help calibrate and validate the observations from the new Geostationary Lightning Mapper operating on NOAA's GOES geostationary weather satellites.

LIS is currently in extended operations.

Recent Achievements

LIS successfully completed four years on orbit in FY 2021. Publication of additional scientific results occurred in major research journals, including an updated global climatology of lightning spanning 1995-present. The LIS instrument team released a new version of its data with improved accuracy. Comparisons of LIS observations with those of the Geostationary Lightning Mappers on NOAA's GOES-16/17 weather satellites continued to help cross-validate both systems.

TOTAL SOLAR IRRADIANCE SENSOR-1 (TSIS-1)

Launched in December 2017, TSIS-1 is currently in its prime operating mission, providing absolute measurements of total solar irradiance (TSI) and spectral solar irradiance (SSI) important for accurate scientific models of climate change and solar variability. TSIS-1 is comprised of two instruments, the Total Irradiance Monitor (TIM) and the Spectral Irradiance Monitor (SIM), which are the most accurate solar irradiance instruments in the world, allowing scientists to better understand solar variability at both short and long-time scales. The Laboratory for Atmospheric and Space Physics (LASP) built a highly sensitive thermal pointing system that the project uses to accommodate the instruments on the ISS.

Recent Achievements

The TSIS-1 instruments on the ISS continue to track daily TSI and SSI variations with unprecedented accuracy and precision. In FY 2021, the TIM extended the TSI record to 42 years and observed a gradual increase in TSI during 2019-2021 as the Sun entered Solar Cycle 25. The climate quality TSI record continues to support the Intergovernmental Panel on Climate Change (IPCC) assessment that the Sun did not cause recent global warming. The SIM continued to acquire the SSI data over the broad spectral range started by Solar Radiation and Climate Experiment (SORCE, 2003-2020) and extended the SSI record to 18 years with much improved accuracy in the visible (VIS) and near infrared (NIR) wavelengths. TSIS-1 measurements in the 2019 solar minimum established a new solar reference spectrum, which is the most accurate to date. Measuring the incoming solar energy at different spectral wavelengths provides critical elements for understanding how the Earth's atmosphere and surface absorb that energy. Modeled Arctic sea ice extent and surface temperature showed significant differences when using the new and old solar spectra.

OTHER MISSIONS AND DATA ANALYSIS

DEEP SPACE CLIMATE OBSERVATORY (DSCOVR)

DSCOVR, which launched in February 2015, is a multi-agency (NOAA, United States Air Force, and NASA) mission with the primary goal of making unique space weather measurements from the Lagrange point L1. Lagrange point L1 is on the direct line between Earth and the Sun and provides about a 45-minute early warning for adverse space weather events. NASA provided the two Earth-observing instruments, the Earth Poly-Chromatic Imaging Camera (EPIC) and the National Institute of Standards and Technology Advanced Radiometer (NISTAR), to the DSCOVR satellite. NASA-processed EPIC and NISTAR data has been publicly available since June 2015 and includes color images of the full sunlit disk of the Earth; maps of ozone, clouds, aerosols, and vegetation; and measurements of sulfur dioxide from volcanic eruptions.

The DSCOVR NASA provided instruments are currently in extended operations.

Recent Achievements

In FY 2021, the DSCOVR project developed two new publicly available products: solar glints and ocean surface photosynthetically available radiation which is the amount of light available for photosynthesis and is related to ocean chlorophyll. The sun glints caused by the specular reflection of sunlight from highly reflective objects provide excellent opportunities to learn about ice clouds that cause the glints. It typically takes 24 to 36 hours to make Level 2 data products publicly available. The DSCOVR team has improved this turnaround and made important UV aerosol data related to forest fires available in 12-24 hours after EPIC observations. EPIC Volcanic SO_2 product in 2020-2021 detected many new volcanic eruptions. The explosive eruption of La Soufrière (St. Vincent Island in the Caribbean Sea) in April 2021 was the largest tropical eruption detected by the DSCOVR mission to date. Volcanic ash impacted SO_2 retrievals in the La Soufrière eruption cloud and the project is planning aerosol corrections for the next iteration of the EPIC volcanic SO_2 product.

LANDSAT 9

The Landsat data series, initiated in 1972, is the longest continuous record of changes in Earth's surface as seen from space and the only U.S. satellite system designed and operated to make repeated observations of the global land surface at moderate resolution. Landsat data is available at no cost to users, providing a unique resource for people who work in agriculture, geology, forestry, regional planning, education, mapping, and climate research.

The Landsat 9 mission extends the record of multi-spectral, moderate resolution Landsat quality data and meets operational and scientific requirements for observing land use and land change. Landsat 9 is a collaboration between NASA and the USGS and is a cornerstone of our Nation's multi-satellite, multi-decadal, Sustainable Land Imaging (SLI) effort. SLI is a NASA-Department of the Interior (DOI)/USGS partnership to develop, launch, and operate a spaceborne system and provide researchers and users with high quality, global, continuous land imaging measurements that are compatible with the existing 49-year Landsat record and will evolve through investing in and introducing new sensor and system technologies.

Recent Achievements

NASA successfully launched Landsat 9 from Vandenberg Space Force Base on September 27, 2021. Commissioning activities were completed in January 2022. Following commissioning and the successful completion of the on-orbit acceptance review and post launch assessment review, the project will hold the

OTHER MISSIONS AND DATA ANALYSIS

mission transition and handover review. Following the mission transition and handover review, responsibility of the Landsat 9 mission operations transfers from NASA to the USGS. NASA will continue to support Landsat 9 data calibration, validation, and characterization throughout the life of the mission.

EARTH SYSTEM EXPLORERS

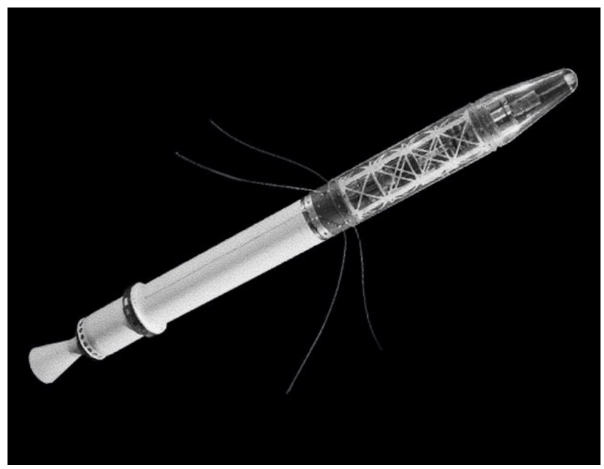
FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**0.0**	**6.6**	**23.4**	**36.3**	**92.0**	**150.2**	**251.3**
Change from FY 2022 Budget Request			**16.8**				
Percent change from FY 2022 Budget Request			**254.5%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

NASA's Earth System Explorers program provides competitive opportunities for medium-sized instruments and missions that address specific science and applications needs identified in the 2017 National Academies' report "Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space."



NASA's Earth System Explorers will continue the tradition of the first U.S. satellite Explorer 1 (illustrated above), launched in 1958.

These Principal Investigator (PI)-led projects will employ innovative, streamlined, and efficient management approaches to constrain design, development, and operations costs. Distinct from Earth Venture instruments and missions, Earth System Explorers will focus on one or more of the seven identified targeted observables, important to our understanding of Earth system science:

- Atmospheric winds;
- Greenhouse gases;
- Ice elevation;
- Ocean surface winds and currents;
- Ozone and trace gases;
- Snow depth and snow water equivalent; and
- Terrestrial ecosystem structure.

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

ACHIEVEMENTS IN FY 2021

None. Budget did not exist in FY 2021.

EARTH SYSTEM EXPLORERS

WORK IN PROGRESS IN FY 2022

In October 2021, NASA released the Community Announcement concerning its intention to issue an Announcement of Opportunity (AO) for the new Earth System Explorers Program. NASA plans to release the draft AO in April 2022, with the final AO planned for release by the end of FY 2022. The AO will solicit proposals for new PI-led missions investigating one or more of the 2017 Decadal Survey Earth System Explorer Targeted Observables.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

Proposal responses to the AO will be due 90 days after its release. NASA plans to make approximately 4 selections for competitive Phase A studies in the fourth quarter of FY 2023. Missions selected through this AO will be the first in the Earth System Explorers Program. NASA plans to issue AOs for Earth System Explorers every three years.

Program Elements

EARTH SYSTEM EXPLORERS' FUTURE MISSIONS

Earth System Explorers Future Mission funding supports the selection of new missions through AO solicitations every three years to support the goal of launching three missions within a decade. This funding supports proposals selected during Step 1 of the proposal process to conduct Phase A formulation studies. Selected proposals will move to Step 2 for full mission implementation.

EARTH SYSTEM EXPLORERS PROGRAM MANAGEMENT

Earth System Explorers Program Management provides for the development of AO solicitations and the technical, management, and cost evaluations of proposals received in response to the AO solicitations. It also supports management of missions conducting formulation studies and missions in implementation, per the two-step selection process.

Program Schedule

Date	Significant Event
Q1 FY 2022	AO release
Q4 FY 2023	Selection of candidates to move into Step 1 within nine months of receipt of proposals
Q1 FY 2024	Select proposals for Step 2 after 9-14 months

EARTH SYSTEM EXPLORERS

Program Management & Commitments

Program Element	Provider
Earth System Explorers Program Management	Provider: TBD Lead Center: TBD Performing Center(s): TBD Cost Share Partner(s): TBD

Acquisition Strategy

NASA will issue AO solicitations for Earth System Explorers every three years to support the goal of launching three missions within a decade. NASA will select all Earth System Explorers through full and open competition using a two-step proposal process.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

None.

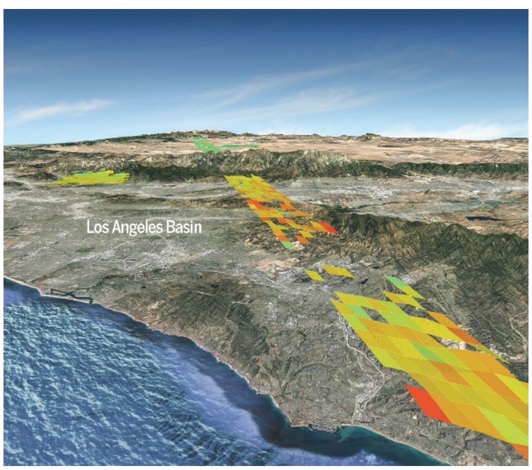
EARTH SYSTEM SCIENCE PATHFINDER

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Venture Class Missions	200.7	226.4	**194.5**	146.3	125.7	167.7	181.9
MAIA	17.5	70.0	**13.1**	26.5	20.2	1.7	0.6
GeoCarb	16.1	39.7	**47.6**	49.0	43.8	9.4	6.7
Other Missions and Data Analysis	52.5	54.9	**53.3**	52.9	47.8	40.5	41.2
Total Budget	**286.8**	**391.0**	**308.4**	**274.8**	**237.5**	**219.3**	**230.4**
Change from FY 2022 Budget Request			**-82.6**				
Percent change from FY 2022 Budget Request			**-21.1%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



OCO-2 provides an unprecedented view from space of how carbon dioxide emissions vary within individual cities such as Los Angeles and its surroundings, as shown here. Concentrations vary from more than 400 parts per million (red) over the city, to the high 300s (green) over the desert.

The Earth System Science Pathfinder (ESSP) program provides regular competitively selected Earth science research opportunities that accommodate new and emerging scientific priorities and measurement capabilities. This results in a series of relatively low-cost, small-sized investigations and missions. Principal investigators lead these focused projects that contribute to studies of the atmosphere, oceans, land surface, polar ice regions, or solid Earth.

ESSP projects include space missions, remote sensing instruments for space-based missions of opportunity, and extended duration airborne-science missions. The ESSP program also supports the conduct of science research utilizing data from these missions. ESSP projects may involve partnerships with other United States agencies and/or international organizations. This portfolio of missions and investigations provides opportunity for investment in innovative Earth science that enhances NASA’s capability for better understanding the current state of the Earth system.

Earth System Science Pathfinder

Explanation of Major Changes in FY 2023

NASA anticipates cost growth in the lifecycle cost of the Multi-Angle Imager for Aerosols (MAIA) mission and the GeoCarb mission. More details are provided in the MAIA and GeoCarb sections of this document. In addition, this budget request includes an investment to procure a replacement aircraft for the DC-8 in Earth Venture Management. This investment enables NASA to maintain essential core airborne capabilities.

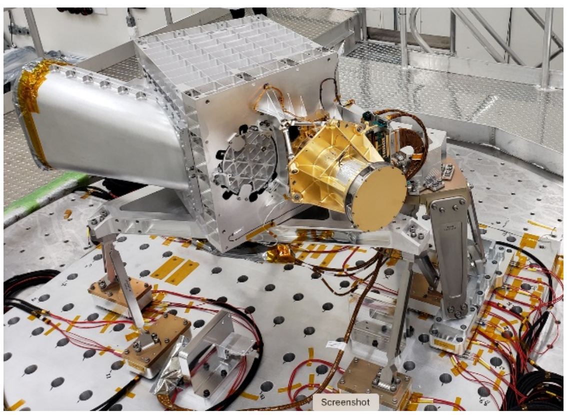
VENTURE CLASS MISSIONS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**200.7**	**226.4**	**194.5**	**146.3**	**125.7**	**167.7**	**181.9**
Change from FY 2022 Budget Request			**-31.9**				
Percent change from FY 2022 Budget Request			**-14.1%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



Shown above is the EMIT optical system during the preparation for tests to simulation the vibrations seen during the launch to space. The grey box holds the telescope which defines the view of the Earth, and the gold component is the spectrometer which separates the colors of light to allow scientists to determine the minerals on the surface in the arid regions targeted by EMIT.

NASA's Earth Venture Class Missions provide frequent flight opportunities for high-quality, low-cost earth science investigations that can be developed and flown in five years or less. NASA selects the investigations through open competitions to ensure broad community involvement and encourages innovative approaches. Successful investigations enhance our capability to understand the current state of the Earth system and enable continual improvement in the prediction of future changes. Solicitations include both space-borne and airborne/suborbital opportunities.

NASA established Venture Class Missions in response to recommendations in the 2007 National Academies' report, "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond." The 2017 National Academies' report, "Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space," also endorses the Venture Class Missions.

The Earth Venture Class Missions include four components:

- Earth Venture Instruments (EVI) are missions of opportunity hosted on space-borne platforms. NASA releases EVI solicitations every three years at a cost cap of approximately $108 million in FY 2022 dollars.
- Earth Venture Suborbital (EVS) investigations, which are sustained suborbital-science investigations. NASA releases EVS solicitations every four years with a budget of approximately $133 million in FY 2022 dollars, and selects multiple investigations within each call, individually cost-capped at no more than $30 million.

VENTURE CLASS MISSIONS

- Earth Venture Continuity (EVC) will fly on-orbit demonstrations of affordable measurement approaches for maintaining the long-term record of important Earth science measurements. NASA will release EVC solicitations every three years at a cost cap of approximately $166 million in FY 2022 dollars.
- Earth Venture Missions (EVM) are small space-based missions. NASA releases EVM solicitations every four years at a cost cap of approximately $190 million in FY 2022 dollars.

The cadence of solicitations for EVI and EVC investigations will alternate every 18 months, releasing each approximately every three years. The cadence of EVS and EVM solicitation is independent of other Earth Venture solicitations.

EXPLANATION OF MAJOR CHANGES IN FY 2023

NASA anticipates cost growth in the life cycle cost of the Multi-Angle Imager for Aerosols (MAIA) mission and the GeoCarb mission. Details are provided in the MAIA and GeoCarb sections of this document. In addition, this budget request includes an investment to procure a replacement aircraft for the DC-8 under the Earth Venture Management project. NASA will also delay the cadence for Earth Venture Suborbital, Earth Venture Instrument, and Earth Venture Class by one year to incorporate outcomes from the National Academies of Sciences, Engineering, and Medicine (NASEM) Earth Venture Program study and to address access to space challenges.

Funding needs are reduced in FY 2023 compared to FY 2022 due to a one-time procurement in FY 2022 for replacement DC-8 aircraft, MAIA access-to-space hosting costs in FY 2022, and ramp down of development activities for Tropospheric Emissions: Monitoring of Pollution (TEMPO) as the project approaches launch.

NASA selected Investigation of Convective Updrafts (INCUS) through the Agency's Earth Venture Mission-3 (EVM-3) solicitation in November 2021 to study the behavior of tropical storms and thunderstorms, including their impacts on weather and climate models. NASA expects to launch INCUS in 2027 as part of NASA's Earth Venture Program.

Program Element

VENTURE CLASS FUTURE MISSIONS

Earth Venture Class Future Mission funding supports the selection of new missions through Announcement of Opportunity (AO) solicitations at intervals of every four years for EVS and EVM; EVI and EVC will alternate every 18 months, each released approximately every three years. NASA released EVM-3 AO in November 2020 and plans to release a solicitation for EVI-6 in FY 2022.

CYCLONE GLOBAL NAVIGATION SATELLITE SYSTEM (CYGNSS) (EVM-1, SELECTED IN 2012)

CYGNSS data enables scientists to probe from space key air-sea interaction processes that take place near the inner core of the storms and play large roles in the genesis and intensification of hurricanes. The

VENTURE CLASS MISSIONS

CYGNSS measurements also provide information to the hurricane forecast community, potentially enabling better modeling to predict the strength of hurricanes as they develop. CYGNSS also makes measurements over land that scientists use to image flood inundation, wetland extent, and surface soil moisture.

CYGNSS's eight micro-satellite observatories receive both direct and reflected signals from Global Positioning System (GPS) satellites. The direct GPS signals pinpoint CYGNSS observatory positions and track fluctuations in GPS power, while the reflected signals are indicative of ocean surface roughness. Scientists use both measurements to derive the critical measurement of wind speed over ocean and water properties over land. CYGNSS launched in December 2016 and entered its extended mission phase in March 2019.

Recent Achievements

The CYGNSS team upgraded an existing soil moisture validation site in Colorado and initiated new validation sites in New Zealand, in partnership with the New Zealand Space Agency, and New Mexico. The CYGNSS team will use these sites to validate and characterize the performance of the new CYGNSS soil moisture data products. The CYGNSS team used the data products to detect and image ocean microplastic concentration, resolve unexpected seasonal variations of the concentration in the Great Pacific Garbage Patch, and detect outflow plumes from the mouths of major rivers. The NOAA Hurricane Research Division (HRD) conducted observing system experiments to evaluate the impact of NASA CYGNSS wind speed measurements in hurricane prediction models. The results of this evaluation and recent publications demonstrate a significant positive impact on the forecasting of storm intensity (e.g., maximum wind speed) and a smaller, though still positive, impact on the prediction of storm track (e.g., where the storm center will go) when CYGNSS measurements are used in these models.

Planned Future Achievements

The CYGNSS team will release an improved version of the ocean surface wind speed science data product with significantly improved performance at high, storm force, wind speeds. They will release a new soil moisture data product that includes comprehensive performance characterization for use in hydrological research and water resource applications. Additionally, the CYGNSS team will release a new ocean microplastic concentration data product in coordination with the United Nations Educational, Scientific, and Cultural Organization (UNESCO)/International Ocean-Colour Coordinating Group Task Force on the Remote Sensing of Marine Litter and Debris. NOAA HRD will expand its study of hurricane forecast impact using NASA CYGNSS data, with an overall objective of vetting the new CYGNSS technique for measuring hurricane winds for eventual operational use.

TROPOSPHERIC EMISSIONS: MONITORING OF POLLUTION (TEMPO) (EVI-1, SELECTED IN 2012)

The TEMPO instrument will measure atmospheric pollution covering most of North America. A commercial communications satellite will host the instrument and launch in 2023. On an hourly basis, TEMPO will measure atmospheric pollution spanning from Mexico City to the Canadian tar/oil sands, and from the Atlantic Ocean to the Pacific Ocean. TEMPO will provide measurements that include the key elements of air pollution chemistry (e.g., ozone, nitrogen dioxide) in the lowest part of the atmosphere. Measurements from geostationary orbit will capture the inherent high variability in the daily cycle of emissions and chemistry. Measuring across both time and space will create a revolutionary dataset that provides understanding and improves prediction of air quality and climate forcing.

VENTURE CLASS MISSIONS

Maxar Technologies of Westminster, Colorado will provide satellite integration, launch, and data transmission services for TEMPO.

Recent Achievements

In May 2021, TEMPO held a successful Hosted Payload System Integration Review. Ball Aerospace and Technologies shipped the TEMPO instrument to Maxar, the host vendor hosting the instrument on the Intelsat 40e satellite, in May 2021. Progress continues on-site at Maxar; TEMPO successfully installed the instrument control electronics on the Intelsat 40e satellite in July 2021 and completed TEMPO's sensor integration with the satellite in November 2021.

Planned Future Achievements

In FY 2022, thermal vacuum testing and spacecraft performance testing will take place. The project planned the operations readiness review for October 2022. The TEMPO project will hold the pre-ship review and ship to the launch site in early FY 2023.

ECOSYSTEM SPACEBORNE THERMAL RADIOMETER EXPERIMENT ON SPACE STATION (ECOSTRESS) (EVI-2, SELECTED IN 2014)

ECOSTRESS launched in June 2018 to help scientists observe changes in global vegetation from the ISS. The sensors give scientists new ways to see how changes in climate or land use affect forests and ecosystems. ECOSTRESS uses a high-resolution thermal infrared radiometer to measure plant evapotranspiration and the loss of water from growing leaves and evaporation from the soil. This data reveals how ecosystems change with climate and provide a critical link between the water cycle and effectiveness of plant growth, both naturally and agriculturally. ECOSTRESS is currently in extended operations.

Recent Achievements

ECOSTRESS collected over 224,000 scenes (images that are 400km by 400 km in size) and achieved an acquisition rate that is more than double the proposed acquisition rate. The data show variations in plant water use and plant stress over different regions, together with differences in plant water uptake over the daily cycle. Companies incorporated ECOSTRESS data into systems used by farmers to optimize irrigation schedules for crops throughout the world. Large cities, such as Los Angeles, are using ECOSTRESS data for heat island assessment and mitigation strategies, and scientists are using the data to detect droughts throughout the world. A heat island is an urbanized area that experiences higher temperatures than outlying areas.

Planned Future Achievements

The project will continue extended operations through September 2023. An expanded science team will use the ECOSTRESS data for a variety of studies in agriculture, forestry, geology, and the environment.

GLOBAL ECOSYSTEM DYNAMICS INVESTIGATION (GEDI) LIDAR (EVI-2, SELECTED IN 2014)

GEDI is a geodetic-class laser ranging system that provides three-dimensional measurements of the Earth’s forests from the ISS. GEDI measures the height of the Earth’s temperate and tropical forests and their vertical structure. This data will help scientists determine, for the first time, how much carbon forests store as biomass, and the net impact of deforestation and subsequent regrowth on atmospheric carbon dioxide that results from human-influenced activities and climate variations. GEDI is the first mission optimized for vegetation measurements from space and provides the first global and transparently available data set that various United States agencies can use at relevant scales for both policy and land management. Launched in December 2018, GEDI completed its prime mission in April 2021 and is currently in an extended operations phase.

Recent Achievements

GEDI collected over ten billion observations of the Earth's forests and topography during its two-year prime mission and continues to expand its observational archive, which now spans 30 months. GEDI's contractual data sets are publicly available at the Land Processes Distributed Active Archive Center (DAAC) and the Oak Ridge National Laboratory (ORNL) DAAC. Scientists have used these data sets to make the most complete maps to date for forest height, canopy cover, bare earth topography, and GEDI's key product, aboveground biomass. The biomass products, at 25 m and 1 km resolutions, provide the baseline carbon inventory for the United States and the 120 other countries that GEDI observes. The biomass products supplement existing national forest inventories and, in many cases, provide the only inventories available for some countries. Initial analyses from GEDI show almost 25 percent more carbon on the land surface than estimated from existing national forest inventories as reported to the Food and Agriculture Organization of the United Nations. Researchers will use these biomass maps to quantify the impact of fires, deforestation, and other disturbances on atmospheric carbon dioxide concentrations. The project continues to collaborate with the German Aerospace Center (DLR) to fuse GEDI observations with the commercial archive of the DLR TanDEM-X radar satellites and has produced high resolution maps of height and biomass over Gabon, Mexico, Australia, and the Amazon Basin.

Planned Future Achievements

NASA has currently scheduled GEDI's extended mission to last at least through January 2023, and possibly through FY 2023 depending on space availability on the ISS. During its extended mission, GEDI will continue to produce its core data sets, achieving higher accuracy and increased spatial resolution. This is especially true for the bare earth topographic map that GEDI produces with its unique ability to see the ground beneath dense forests as no other sensor can, in addition to inland water bodies, rivers and land ice. GEDI will create new data products, including: a canopy structural complexity index that should be extraordinarily useful for habit and biodiversity studies; data products that blend observations from the ICESat-2 mission and GEDI; fusion of its data with those from TanDEM-X that goes beyond height to 3D canopy structure; and ecosystem modeling that predicts annual land surface carbon sources and sinks. GEDI is working closely with the U.S. Forest Service toward the use of GEDI data for wildfire prediction, habitat management, and national carbon accounting, among other activities.

EARTH VENTURE MANAGEMENT

Earth Venture Management provides the development of AO solicitations and the Technical, Management, and Cost evaluations of proposals received in response to the AO solicitations. Additionally, it supports the airborne assets that the EVS investigations rely on for their airborne campaigns.

VENTURE CLASS MISSIONS

TIME-RESOLVED OBSERVATIONS OF PRECIPITATION STRUCTURE AND STORM INTENSITY WITH A CONSTELLATION OF SMALLSATS (TROPICS) (EVI-3, SELECTED IN 2016)

TROPICS will make measurements over the tropical latitudes to observe the thermodynamics and precipitation structures of Tropical Cyclones (TCs) over much of the storm systems' lifecycles. TROPICS will take measurements of the temperature within the atmosphere, spatially and vertically resolved, as well as humidity, cloud ice, precipitation horizontal structure, and instantaneous surface rain rates. These measurements and the increased temporal resolution provided by the CubeSat constellation will enable better understanding of the TC lifecycles and the environmental factors that affect the intensification of TCs.

The TROPICS mission consists of six CubeSats, which will each have a cross-track scanning multiband passive microwave radiometer in a 1U payload (1U, a CubeSat unit, is equivalent to a 4-inch cubic box).

Recent Achievements

In FY 2021, NASA successfully launched the TROPICS Pathfinder CubeSat into a sun synchronous orbit during SpaceX's Transporter-2 mission, as a risk reduction experiment. The team converted the TROPICS Pathfinder CubeSat, the qualification unit, which is identical to the TROPICS Constellation CubeSats, into a flight unit enabling NASA to test the system from end-to-end prior to the constellation launches. During the commissioning phase, the TROPICS Pathfinder captured high quality images and data products from Hurricanes Ida and Sam in the Atlantic, as well as from the Category 5 Super Typhoon Mindulle in the Pacific. The NASA Launch Services Program successfully awarded a contract to Astra Space, Inc. for three separate launches to deploy the six CubeSats of the TROPICS Constellation in FY 2022.

Planned Future Achievements

The TROPICS Pathfinder will continue its risk reduction mission in FY 2022 and will conduct a NOAA-funded Low Latency Data Demonstration. The TROPICS team will incorporate lessons from the Pathfinder mission into the final design for the six CubeSats intended for the TROPICS Constellation. Astra Space, Inc., will launch the six TROPICS Constellation CubeSats to a 30-degree inclination orbit in pairs on-board three separate launch vehicles in FY 2022.

EARTH VENTURE SUBORBITAL-3 (EVS-3; SELECTED IN 2018)

In 2020, NASA initiated five investigations spanning a range of pressing research areas such as intense East Coast snowfall events and the impact of small-scale ocean currents on global climate. These investigations are:

- Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) studies the formation of snow bands in East Coast winter storms. Better understanding of the mechanisms of snow band formation and the factors that influence the location of the most intense snowfall will help improve forecasts of these extreme weather events.
- Aerosol Cloud Meteorology Interactions over the Western Atlantic Experiment (ACTIVATE) identifies how aerosol particles change cloud properties in ways that affect Earth's climate system. The investigation will focus on marine boundary layer clouds over the western North Atlantic Ocean that have a critical role in our Earth's energy balance.

VENTURE CLASS MISSIONS

- Delta-X investigates the natural processes that maintain and build land in major river deltas threatened by rising seas. The project will improve models that predict loss of coastal land from sea level rise by improving estimates of how deltas add land—a process that involves trapping sediments and creating organic soils as plants grow.
- Dynamics and Chemistry of the Summer Stratosphere (DCOTSS) explores how strong summertime convective storms over North America can change the chemistry of the stratosphere. These storms regularly penetrate deep into the lower stratosphere, carrying pollutants that can change the chemical composition of this atmospheric layer, including ozone levels.
- Sub-Mesoscale Ocean Dynamics and Vertical Transport (S-MODE) examines the potentially large influence that small-scale ocean eddies have on the exchange of heat between the ocean and the atmosphere. The project will collect a benchmark data set of climate and biological variables in the upper ocean that influence this exchange.

Recent Achievements

In FY 2021, the ACTIVATE investigation successfully conducted its third and fourth deployments out of NASA Langley Research Center. The DCOTSS investigation successfully conducted its first deployment out of Salina, KS. Both ACTIVATE and DCOTSS continue to hold science team meetings and open data workshops virtually due to the ongoing COVID-19 Pandemic.

The Delta-X investigation successfully conducted deployments out of Louisiana. Delta-X completed both the high discharge and low discharge field campaigns in 2021. There are no more field deployments remaining, with Delta-X focused on data analysis, science analysis and archival activities. Delta-X held a virtual open data workshop in November 2021, and a hybrid science team meeting in December 2021.

DCOTSS held a virtual science team meeting in November 2021.

The IMPACTS investigation conducted a hybrid (in-person and virtual) science team meeting and their second Open Data Workshop in September 2021.

The S-MODE investigation successfully completed its test campaign in May 2021, consisting of science flights on the AFRC B200 aircraft. The test campaign demonstrated joint operations between JPL's DopplerScatt instrument, UCLA's MOSES instrument and WHOI's ocean wave glider. S-MODE successfully completed its pilot campaign mid-October through early November 2021. Future campaigns include instruments on three aircraft, a ship, and multiple autonomous ocean vehicles.

Planned Future Achievements

S-MODE successfully completed its pilot campaign mid-October through early November 2021. Future campaigns include instruments on three aircraft, a ship and multiple autonomous ocean vehicles.

ACTIVATE is planning its final deployments from November 2021 through June 2022 out of LaRC, using the LaRC Falcon and UC12 aircraft.

IMPACTS is conducting its second deployment in January/February 2022 using the WFF P3B out of Wallops Island Flight Facility and the AFRC ER-2 based either in Georgia or North Carolina.

The Delta-X team will continue to focus on data processing and analysis. DCOTSS will focus on planning for its second science deployment in April 2022.

VENTURE CLASS MISSIONS

EARTH SURFACE MINERAL DUST SOURCE INVESTIGATION (EMIT) (EVI-4; SELECTED IN 2018)

EMIT will use a sensor mounted to the exterior of the ISS to determine the mineral composition of natural sources that produce dust aerosols around the world. Scientists do not currently have a global inventory of the natural mineral sources of dust, and as a result, the global impacts of dust on weather, atmospheric circulation, and other aspects of Earth's environment are not well established.

EMIT's hyperspectral instrument will measure the different wavelengths of light emitted by minerals on the surface of deserts and other dust sources to determine their composition. By measuring in detail which minerals make up the dust, EMIT will help answer the critical question of whether mineral-based dust has a cooling or warming effect on the atmosphere. EMIT's modeling component will use the data collected to advance the understanding of the role of atmospheric dust in Earth's climate and better predict how it can be expected to change in the future.

Recent Achievements

The EMIT project encountered significant challenges soon after KDP-C in January 2020, due to the COVID-19 pandemic, when Jet Propulsion Laboratory (JPL) closed their facilities, stopping all hands-on hardware work between March and June 2020. The subsequent limited restart of on-site activities allowed project on-site work to resume, using safe-at-work protocols, but at a less efficient pace. The EMIT project also encountered significant schedule delays in receiving flight hardware from different vendors due to COVID-19 at vendor facilities, which had significant cost impacts. Consequently, the project breached the ABC life cycle cost. In April 2021, and again in February 2022, NASA approved additional funding to complete the mission and established a new Agency Total lifecycle cost. Vendors delivered all flight hardware to JPL and the project has been working to complete integration and testing of the instrument.

Planned Future Achievements

The EMIT project will continue instrument integration and test activities in FY 2022, maintaining safe-at-work protocols at JPL. EMIT expects to deliver the instrument to KSC in FY 2022 for a launch to ISS in October 2022.

POLAR RADIANT ENERGY IN THE FAR INFRARED EXPERIMENT (PREFIRE) (EVI-4; SELECTED IN 2018)

NASA plans to launch PREFIRE in FY 2023. PREFIRE will fly miniaturized thermal spectrometers on a pair of small CubeSat satellites to measure far-infrared emissions and how they change throughout the day and over seasons. These CubeSats will orbit Earth's poles to probe a little-studied portion of the radiant energy emitted by Earth for clues about Arctic warming, sea-ice loss, and ice-sheet melting. These observations will allow scientists to assess how changes in thermal infrared emissions at the top of Earth's atmosphere are related to changes in cloud cover and surface conditions below, such as the amount of sea ice and meltwater on the surface of ice.

Recent Achievements

The PREFIRE project successfully completed its critical design review in June 2021. Assembly continues for the CubeSat chassis, with instrument integration expected in 2022. The project continues to make progress toward delivery of subsystems to instrument integration and test including instrument assembly related to optics, electronics, the focal plane, and pointing mirror.

Planned Future Achievements

The PREFIRE project will hold its systems integration review and pre-ship review in FY 2022. The project will deliver the instruments to the CubeSat vendor Blue Canyon Technologies (BCT) for integration in FY 2022.

GEOSYNCHRONOUS LITTORAL IMAGING AND MONITORING RADIOMETER (GLIMR) (EVI-5; SELECTED IN 2019)

GLIMR will provide unique observations of ocean biology, chemistry, and ecology in the Gulf of Mexico, portions of the southeastern United States coastline, and the Amazon River plume – where the waters of the Amazon River enter the Atlantic Ocean. It will closely monitor the health of our oceans and assess risks for coastal communities to protect our environment.

NASA will integrate GLIMR on a NASA-selected platform and launch in the 2026-2027 timeframe into a geosynchronous orbit, where it will monitor a wide area centered on the Gulf of Mexico for up to 15 hours a day. From this vantage point, the hyperspectral ocean color radiometer will measure the reflectance of sunlight from optically complex coastal waters in narrow wavebands. GLIMR will gather observations of a given area each day in a way that would not be possible from a satellite in a low-Earth orbit. These observations are a critical capability in studying phenomena such as the lifecycle of coastal phytoplankton blooms and oil spills.

Recent Achievements

NASA LaRC established the contract vehicle with the Principal Investigator's institution, the University of New Hampshire, in FY 2021 and completed the SRR/mission definition review in December 2021.

Planned Future Achievements

The project plans to complete the PDR/ in FY 2022.

LIBERA (EVC-1; SELECTED IN 2020)

Libera is NASA’s first mission selected under the EVC element. The project, named for the daughter of Ceres in ancient Roman mythology, provides continuity of the Clouds and the Earth’s Radiant Energy System (CERES) Earth Radiation Budget (ERB) observations. Its primary goal is to extend the ERB record seamlessly, essential for recognizing changes to Earth’s climate system and for constraining future predictions. NOAA's JPSS-3 satellite will host the Libera instrument after launch in 2028.

Recent Achievements

Libera successfully completed the system requirements review (SRR)/instrument definition review in February 2021. Following a successful Key Decision Point B (KDP-B) in April 2021, the project entered the preliminary design and technology completion phase.

VENTURE CLASS MISSIONS

Planned Future Achievements

The Libera project's instrument's detectors reached technology readiness level-6 and passed the preliminary design review in February 2022. The KDP-C confirmation review will follow the PDR in April 2022.

INVESTIGATION OF CONVECTIVE UPDRAFTS (INCUS) (EVM-3, SELECTED IN 2021)

INCUS will study the behavior of tropical storms and thunderstorms, including their impacts on weather and climate models, by directly addressing why convective storms, heavy precipitation, and clouds occur exactly when and where they form. The investigation stems from the 2017 Earth Science Decadal Survey and fills an important niche to help understand extreme weather and its impact on climate models – all of which serve to provide crucial information needed to mitigate weather and climate effects on our communities. INCUS means anvil in Latin and is a reference to the anvil shaped cumulonimbus thunderstorm clouds it will study.

Recent Achievements

NASA selected INCUS in November 2021 through the Agency’s Earth Venture Mission-3 (EVM-3) solicitation that sought complete, space-based investigations to address important science questions and produce data of societal relevance within the Earth science field.

Planned Future Achievements

NASA will finalize the contract with Colorado State University for the INCUS project in FY 2022 and provide Authorization to Proceed. INCUS will conduct an SRR/mission definition review followed by a Key Decision Point B (KDP-B) in FY 2023 that allows the project to enter the preliminary design and technology completion phase.

Program Schedule

Date	Significant Event
FY 2022	EVS-4 (suborbital) solicitation released
FY 2022	MAIA instrument delivery
FY 2022	EMIT instrument delivery
FY 2022	Libera Confirmation Review
FY 2022	TROPICS launch readiness
FY 2023	EMIT launch readiness
FY 2023	GeoCarb instrument delivery
FY 2023	EVC-2 (Continuity Measurement) solicitation released
FY 2023	TEMPO launch readiness
FY 2023	PREFIRE CubeSat delivery

VENTURE CLASS MISSIONS

Date	Significant Event
FY 2023	PREFIRE launch readiness
FY 2024	EVI-7 (instrument) solicitation released
FY 2025	EVM-4 (mission) solicitation released
FY 2025	EVC-3 (Continuity Measurement) solicitation released
FY 2026	EVS-5 (suborbital) solicitation released
FY 2026	Libera instrument delivery
TBD	MAIA launch readiness
TBD	GeoCarb launch readiness

Program Management & Commitments

The Earth System Science Pathfinder (ESSP) program at LaRC manages the Venture Class projects. The "Provider" in the following table lists the PI institution for each project.

Program Element	Provider
EVS-3: IMPACTS	Provider: University of Washington Lead Center: LaRC Performing Center(s): ARC, AFRC, GSFC Cost Share Partner(s): N/A
EVS-3: ACTIVATE	Provider: University of Arizona Lead Center: LaRC Performing Center(s): LaRC Cost Share Partner(s): N/A
EVS-3: DCOTSS	Provider: Texas A&M University Lead Center: LaRC Performing Center(s): AFRC, ARC, GSFC Cost Share Partner(s): N/A
EVS-3: S-MODE	Provider: Woods Hole Oceanographic Institute Lead Center: LaRC Performing Center(s): JPL, JSC Cost Share Partner(s): N/A
EVS-3: Delta-X	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A

VENTURE CLASS MISSIONS

Program Element	Provider
EVM-1: CYGNSS	Provider: University of Michigan Lead Center: LaRC Performing Center(s): N/A Cost Share Partner(s): N/A
EVM-2: GeoCarb	Provider: University of Oklahoma Lead Center: LaRC Performing Center(s): ARC, GSFC, JPL Cost Share Partner(s): N/A
EVM-3 INCUS	Provider: Colorado State University Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A
EVI-1: TEMPO	Provider: Smithsonian Astrophysical Observatory Lead Center: LaRC Performing Center(s): LaRC, GSFC Cost Share Partner(s): N/A
EVI-2: ECOSTRESS	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): USDA
EVI-2: GEDI	Provider: University of Maryland Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A
EVI-3: TROPICS	Provider: MIT Lincoln Laboratory Lead Center: LaRC Performing Center(s): GSFC Cost Share Partner(s): N/A
EVI-3: MAIA	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A
EVI-4: EMIT	Provider: JPL Lead Center: JPL Performing Center(s): GSFC, JPL Cost Share Partner(s): N/A

VENTURE CLASS MISSIONS

Program Element	Provider
EVI-4: PREFIRE	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A
EVI-5: GLIMR	Provider: University of New Hampshire Lead Center: LaRC Performing Center(s): LaRC, GSFC Cost Share Partner(s): N/A
EVC-1 LIBERA	Provider: University of Colorado Laboratory for Atmospheric and Space Physics Lead Center: LaRC Performing Center(s): LaRC Cost Share Partner(s): N/A

Acquisition Strategy

NASA will issue Venture Class solicitations at intervals of every four years for EVS and EVM, and every three years for EVI and EVC, alternating every 18 months. NASA will select all Venture Class missions through full and open competition.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
CYGNSS	PI Institution: University of Michigan Instrument Provider: Southwest Research Institute Launch Vehicle Provider: NASA	PI: Ann Arbor, MI Instrument: San Antonio, TX Launch Vehicle: Cape Canaveral, FL
TEMPO	PI Institution: Smithsonian Astrophysical Observatory Instrument Provider: Ball Aerospace & Technologies Corp. Host Services Provider: Maxar Technologies	PI: Cambridge, MA Instrument: Boulder, CO Host Services: Westminster, CO
GeoCarb	PI Institution: University of Oklahoma Instrument Provider: Lockheed Martin Launch Vehicle Provider: TBD	PI Institution: Norman, OK Instrument: Palo Alto, CA Launch Vehicle Provider: TBD
GLIMR	PI Institution: University of New Hampshire Instrument provider: Raytheon Host Services Provider: TBD	PI: Durham, New Hampshire Instrument: El Segundo, CA Host Services: TBD

VENTURE CLASS MISSIONS

Element	Vendor	Location (of work performance)
Libera	PI Institution: University of Colorado Laboratory for Atmospheric and Space Physics Instrument provider: LASP Host Services Provider: NOAA (JPSS-3)	PI: Boulder, CO Instrument: Boulder, CO Host Services: TBD

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	Q2 FY 2020	GeoCarb CDR	Successful	Q2 FY 2024
Performance	SRB	Q4 FY 2020	EMIT CDR	Successful	Q4 FY 2022
Performance	SRB	Q4 FY 2021	PREFIRE CDR	Successful	Q1 FY 2022
Performance	SRB	Q2 FY 2022	Libera PDR	Successful	Q1 FY 2023
Performance	SRB	Q2 FY 2023	PREFIRE ORR	TBD	N/A
Performance	SRB	Q4 FY 2022	EMIT ORR	TBD	N/A
Performance	SRB	Q1 FY 2023	TEMPO ORR	TBD	N/A
Performance	SRB	Q1 FY 2023	Libera CDR	TBD	N/A
Performance	SRB	Q4 FY 2025	GeoCarb ORR	TBD	N/A

MULTI-ANGLE IMAGER FOR AEROSOLS

Formulation	Development	Operations

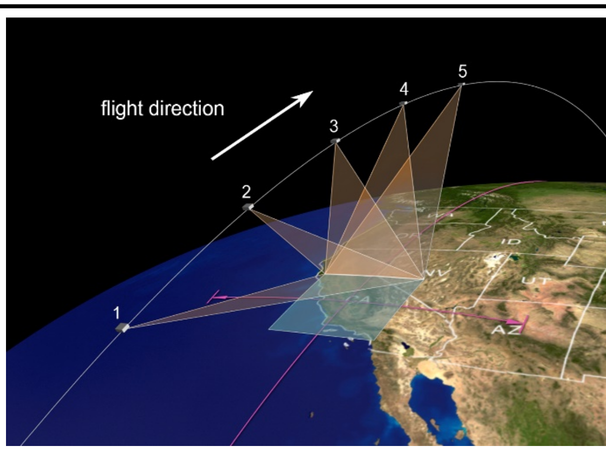
FY 2023 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027	BTC	Total
Formulation	25.4	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	25.4
Development/Implementation	99.1	17.5	70.0	**4.4**	20.7	15.4	0.0	0.0	0.0	227.1
Operations/Close-out	0.0	0.0	0.0	**8.7**	5.9	4.8	1.7	0.6	0.0	21.7
2022 MPAR LCC Estimate	**124.6**	**17.5**	**70.0**	**13.1**	**26.5**	**20.2**	**1.7**	**0.6**	**0.0**	**274.2**
Total Budget	**124.6**	**17.5**	**70.0**	**13.1**	**26.5**	**20.2**	**1.7**	**0.6**	**0.0**	**274.2**
Change from FY 2022 Budget Request				**-56.9**						
Percent change from FY 2022 Budget Request				**-81.3%**						

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The 2022 MPAR LCC Estimate reflects the Fiscal Year 2022 Quarter 1 Financial Report, which is current as of December 2021. The requested budget authority is the project's current budget requirements which have seen programmatic changes approved by NASA since December 2021.



The Multi-Angle Imager for Aerosols (MAIA) represents the first time NASA has partnered with epidemiologists, environmental agencies, and health organizations on a satellite mission aimed at societal benefit and improving lives. The investigation seeks to improve our understanding of how different types of airborne particulate matter affect human health.

PROJECT PURPOSE

The Multi-Angle Imager for Aerosols (MAIA) investigation will use a spaceborne multi-angle imager to remotely determine aerosol characteristics and assess linkages between different airborne particulate matter types and human health (including adverse birth outcomes, cardiovascular and respiratory disease, and premature death). This project will measure concentrations of fine and coarse particles, sulfate, nitrate, organic and elemental carbon, and mineral dust particles in major urban areas around the globe at one-kilometer spatial resolution. The MAIA science team will use established epidemiological methodologies to associate human exposure to particulate matter with adverse health outcomes.

MULTI-ANGLE IMAGER FOR AEROSOLS

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2023

The budget provides an additional $86 million to support anticipated lifecycle cost increases associated with COVID-19 impacts and procurement of a new access-to-space solution. Increased costs for access-to-space delays could vary from a mere schedule delay associated with identifying a solution for a commercial vendor to the purchase of a launch vehicle or spacecraft plus launch vehicle. The MAIA project baseline development costs are currently under review and were not approved prior to publication of the Congressional Justification. The revised cost estimate is expected to exceed $250 million, making it a major project. NASA is in the process of implementing a new acquisition strategy for access to space and will establish an updated schedule and cost for this mission once a solution for the access to space is identified. NASA will notify Congress when a new mission baseline has been approved by the Agency.

PROJECT PARAMETERS

MAIA's primary spaceborne instrument consists of a specialized digital camera mounted on a 2-axis gimbal on a low-Earth orbit spacecraft, which will collect multi-angle spectropolarimetric imagery over a globally distributed set of major metropolitan areas. It will use these data in conjunction with surface-based pollution monitors and atmospheric models to map particulate matter (PM) concentrations and types and to conduct epidemiological studies. Surface-based PM monitoring equipment deployments, overseen by the MAIA project, include instruments that collect particles on filters for subsequent chemical and gravimetric analyses; aethalometers, which measure black carbon concentrations; low-cost PM sensors to extend spatial coverage in selected areas; and aerosol sunphotometers. MAIA's Instrument Operations and Science Data Systems will be located at JPL. The baseline (prime) mission is three years.

ACHIEVEMENTS IN FY 2021

The MAIA instrument is more than 80 percent complete. JPL completed environmental testing of the instrument camera, camera electronics, and on-board calibrator. In addition, the project completed camera calibration and characterization activities (Linear, Geometric, Radiometric, Spectral, and Polarimetric). During FY 2021, "Safe at work" protocols associated with COVID-19 reduced the rate of progress for the MAIA project, delaying instrument delivery beyond expectations at the start of FY 2021.

The project experienced a significant slowdown during FY 2020 and FY 2021 due to the COVID-19 pandemic, particularly for critical path instrument activities. Most of the delay was due to stoppages, disruptions, and inefficiencies of in-lab work at JPL and at most suppliers. Additionally, schedule delays arose due to technical challenges with the access-to-space effort, including an unsuccessful Critical Design Review for the hosting services.

In collaboration with the United States State Department and the United States Agency for International Development (USAID), the MAIA project initiated overseas shipments of the surface-based particulate matter monitoring equipment and installation of the surface monitor network in designated primary target areas and began prelaunch operation of deployed equipment.

The MAIA project updated ground data processing algorithm theoretical basis documents and integrated and tested associated data product generation software.

MULTI-ANGLE IMAGER FOR AEROSOLS

Formulation	Development	Operations

WORK IN PROGRESS IN FY 2022

The Flight Gimbal Assembly will complete environmental testing in FY 2022. The team will complete instrument integration and testing in FY 2022.

NASA successfully completed negotiations for closeout of the hosting services contract for MAIA and began preparations for a new procurement for access-to-space. NASA is assessing the impacts for the Agency development costs and the baseline launch readiness date for MAIA and expects to finalize estimates in FY 2022.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

Following the delivery of the completed MAIA instrument and the initiation of access-to-space procurement in FY 2022, NASA will select an access-to-space provider and establish the necessary project management to begin implementation.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2023 PB Request
KDP-C	Jul 2018	Jul 2018
CDR	May 2019	Jun 2019
Instrument Delivery	Mar 2021	Feb 2022
Launch	Oct 2022	TBD
Start Phase E	Jan 2023	TBD
End Prime Mission	Jan 2026	TBD

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Mile-stone Data	Current Year Milestone Data	Milestone Change (mths)
2019	$130.2	N/A	2022	TBD	N/A	Instrument Delivery	Mar 2021	Feb 2022	+11

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

MULTI-ANGLE IMAGER FOR AEROSOLS

Formulation	Development	Operations

Development Cost Details

This is the first report of development costs for this mission.

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**$130.2**	**TBD**	**TBD**
Aircraft/Spacecraft	38.4	TBD	TBD
Payloads	25.2	45.8	+20.6
Systems I&T	0.0	0.0	0.0
Launch Vehicle	0.0	0.0	0.0
Ground Systems	5.3	7.8	+2.5
Science/Technology	7.3	8.8	+1.5
Other Direct Project Costs	54.0	20.6	-33.5

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Instrument	Payload	Provider: JPL Lead Center: LaRC Performing Center(s): JPL Cost Share Partner(s): None	N/A
Access-to-Space	Access-to-Space	Provider: TBD Lead Center: LaRC Performing Center(s): JPL Cost Share Partner(s): None	N/A

MULTI-ANGLE IMAGER FOR AEROSOLS

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: Development, integration and testing associated with the access-to-space are not ready to support launch, Then: Delays could occur to on-orbit operations.	The MAIA project management team, LaRC, JPL, and Science Mission Directorate management have initiated preparations for a new procurement for access-to-space.
If: Integration and testing associated to the instrument is impacted by additional COVID-19 delays, Then: Delays could occur to on-orbit operations.	The MAIA project management team has revised the integration and test plan to make it more robust and less susceptible to additional COVID-19 impacts.

Acquisition Strategy

NASA selected MAIA in 2016 from the Earth Venture Instrument-3 solicitation. The MAIA hosting services procurement was a competitive procurement. NASA closed the procurement with the vendor in October through mutual agreement after NASA determined after the critical design review that the hosting services being developed would not meet NASA requirements for acceptable risk. NASA is currently reconsidering the acquisition strategy for purchasing hosting services for MAIA. NASA is considering competitively selected commercial services for access to space, opportunities for hosting MAIA on other Government agency missions to include international partners, as well as the possibility of acquiring a spacecraft and launch services for MAIA to provide access to space. NASA plans to identify the acquisition strategy by the end of FY 2022 Q3.

Major Contracts/Awards

Element	Vendor	Location (of work performance)
Instrument	JPL	Pasadena, CA
Access-to-Space	TBD	TBD

MULTI-ANGLE IMAGER FOR AEROSOLS

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	Jun 2016	Instrument SRR	Successful	Apr 2018
Performance	SRB	Apr 2018	Instrument PDR	Successful	Jun 2019
Performance	Senior Review Team (SRT)	Mar 2019	Hosting Services SRR	Successful	Sep 2019
Performance	SRB	Jun 2019	Instrument CDR	Successful	Jul 2022
Performance	SRT	Sep 2019	Hosting Services PDR	Successful	Jun 2021
Performance	SRT	Jun 2021	Hosting Services CDR	Unsuccessful	N/A
Performance	SRB	Jul 2022	Instrument ORR	TBD	TBD

GEOCARB

Formulation	Development	Operations

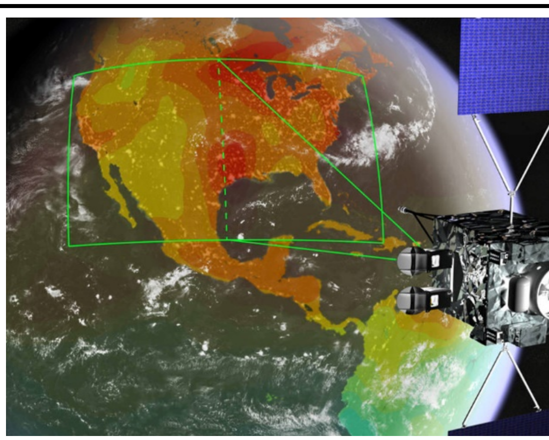
FY 2023 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027	BTC	Total
Formulation	56.9	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	56.9
Development/Implementation	70.5	16.1	39.7	**47.6**	49.0	43.8	2.7	0.0	0.0	269.4
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	6.7	6.7	7.7	21.1
2022 MPAR LCC Estimate	**127.4**	**16.1**	**39.7**	**47.6**	**49.0**	**43.8**	**9.4**	**6.7**	**7.7**	**347.4**
Total Budget	**127.4**	**16.1**	**39.7**	**47.6**	**49.0**	**43.8**	**9.4**	**6.7**	**7.7**	**347.4**
Change from FY 2022 Budget Request				**7.9**						
Percent change from FY 2022 Budget Request				**19.9%**						

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The 2022 MPAR LCC Estimate reflects the Fiscal Year 2022 Quarter 1 Financial Report, which is current as of December 2021. The requested budget authority is the project's current budget requirements which have seen programmatic changes approved by NASA since December 2021.



The goal of the GeoCarb Mission is to observe and advance our scientific understanding of the global carbon cycle. The image above is a rendition of the observatory.

PROJECT PURPOSE

The Geostationary Carbon Cycle Observatory (GeoCarb), a first-of-its-kind space-based Earth science mission, will study how and why the global carbon cycle is changing, and monitor plant health and vegetation stress throughout the Americas from geostationary orbit.

GeoCarb will advance our understanding of Earth's natural exchanges of carbon between the land, atmosphere, and ocean. The primary goals of the mission are to monitor plant health, vegetation stress, and to probe, in unprecedented detail, the natural sources, sinks, and exchange processes that control carbon dioxide, carbon monoxide, and methane in the atmosphere. The 2017 Decadal Survey identified reducing uncertainty in the global carbon cycle by a factor of two to be one of the most important climate science objectives. The 2021 Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report and recent scientific findings have further increased the emphasis on understanding greenhouse gases as a driver of climate. The GeoCarb mission promises to be a transformative capability by providing high-quality measurements of carbon dioxide, methane, and carbon monoxide in the atmosphere, and making direct observations of photosynthetic activity by measuring solar-induced fluorescence.

EXPLANATION OF MAJOR CHANGES IN FY 2023

The budget includes an increase of $117.4 million to the GeoCarb lifecycle cost to cover anticipated COVID-19 pandemic impacts, schedule delays, and higher access-to-space costs. The GeoCarb project baseline development costs are currently under review and were not approved prior to publication of the Congressional Justification. The revised cost estimate is expected to exceed $250 million, making it a major project. FY 2022 budget estimates are provided in the table below. NASA will notify Congress when a new mission baseline has been approved by the Agency.

GeoCarb completed a replan in September 2021, restructuring the project from a Principal Investigator-led mission to a directed mission at Goddard Space Flight Center (GSFC). At the time of the project selection and confirmation, a commercial communication satellite would host the GeoCarb payload, but the provider later withdrew their intent to host GeoCarb due to a change in their business plan. NASA is in the process of implementing a new acquisition strategy for access to space and will establish an updated schedule and cost for this mission once a solution is identified for the access to space.

PROJECT PARAMETERS

GeoCarb is targeted for launch no later than 2024 and will build on the success of NASA's Orbiting Carbon Observatory-2 (OCO-2) mission by placing a similar instrument on a satellite flying in geostationary orbit. Its longitude will allow "wall-to-wall" observations over the Americas between 50 degrees North and South latitude -- from the southern tip of the Hudson Bay to the southern tip of South America. At an altitude of 22,236 miles (35,800 kilometers) above the Americas, GeoCarb will collect 10 million daily observations of the concentrations of carbon dioxide, methane, carbon monoxide and solar-induced fluorescence (SIF) at a spatial resolution of about 3 to 6 miles (5 to 10 kilometers). GeoCarb will complement measurements by OCO-2 and other low-Earth orbiting satellites by filling in data gaps in both time and space.

The GeoCarb mission will make observations over the Americas from an orbit of approximately 22,000 miles (35,400 kilometers) above the equator. GeoCarb will measure the total concentration of carbon dioxide, methane, and carbon monoxide in the atmosphere with a horizontal ground resolution of three to six miles (5 to 10 kilometers). GeoCarb also will measure solar-induced fluorescence, a signal related directly to changes in vegetation photosynthesis and plant stress.

The GeoCarb instrument consists of the aperture assembly, telescope, spectrometer, and electronics boxes. It is a four-Infrared channel, single-slit imaging spectrograph, optimized to deduce concentrations of carbon dioxide, carbon monoxide and methane, and Solar-Induced Fluorescence (SIF) from Geostationary Orbit. The SIF channel will provide valuable information on aerosol and cloud contamination. The prime mission for GeoCarb is three years.

The access to space portion of the mission is under development by NASA in coordination with the University of Oklahoma (OU).

GEOCARB

Formulation	Development	Operations

The Geostationary Carbon Cycle Observatory (GeoCarb), a first-of-its-kind, space-based Earth science mission, will study how and why the global carbon cycle is changing, and monitor plant health and vegetation stress throughout the Americas.

ACHIEVEMENTS IN FY 2021

GeoCarb has completed 98 percent of the drawings and analysis to finalize the instrument design. The project completed the telescope structure and main bench and initiated assembly of hardware and subassembly testing. GeoCarb completed the slit homogenizer flight model testing and confirmed successful mitigation of the non-uniform illumination effects.

WORK IN PROGRESS IN FY 2022

GeoCarb will complete instrument integration and testing and prepare for pre-environment reviews and pre-ship review. NASA will complete the procurement strategy and release a Request for Proposal for access to space.

GeoCarb conducted a replan in September 2021, that incorporated the 2020 decision to restructure the project from a principal investigator-led mission to a directed mission at GSFC. At the time of project selection and confirmation, a commercial communications satellite planned to host the GeoCarb payload, but the provider later withdrew their intent to host GeoCarb due to a change in their business plan. NASA is in the process of implementing a new acquisition strategy for access to space. The NASA replan will establish a new Agency total cost and an updated schedule.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

GeoCarb will complete the instrument and, if necessary, place the instrument into storage until the spacecraft is ready for instrument integration.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2023 PB Request
KDP-C	July 2019	July 2019
CDR	Jan 2020	Jan 2020
Instrument Delivery	N/A	June 2023
KDP-D	June 2022	Nov 2024
Launch (or equivalent)	June 2023	TBD
KDP-E	Mar 2024	TBD
End of Prime Mission	Mar 2027	TBD

GEOCARB

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2020	$156.5	N/A	2022	TBD	TBD	LRD	June 2023	TBD	TBD

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

This is the first report of development cost for this mission.

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**$156.5**	**TBD**	**TBD**
Aircraft/Spacecraft	37.9	TBD	TBD
Payloads	15.8	94.9	+ 79.1
Systems I&T	2.7	0.2	- 2.5
Launch Vehicle	0.1	50.0	+ 49.9
Ground Systems	4.0	4.8	+ 0.8
Science/Technology	5.5	2.6	- 2.9
Other Direct Project Costs	90.5	45.0	- 45.5

Project Management & Commitments

GSFC and the Earth System Science Pathfinder Program (ESSP) provide project management and technical authorities. OU manages GeoCarb science operations and is responsible for science integrity of the mission. The Advanced Technology Center of the Lockheed Martin Space Systems Company is developing the GeoCarb instrument.

GEOCARB

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
GeoCarb Instrument	Consists of a telescope for light collection, optics and grating spectrometer, star trackers, and electronic boxes	Provider: LMATC Lead Center: GSFC/OU Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Spacecraft Bus	Provides Instrument Platform	Provider: TBD Lead Center: TBD Performing Center(s): TBD Cost Share Partner(s): TBD	N/A
Launch Vehicle	Delivers spacecraft to orbit	Provider: TBD Lead Center: TBD Performing Center(s): TBD Cost Share Partner(s): TBD	N/A

Project Risks

Risk Statement	Mitigation
If: Covid-19 impact increases in severity, Then: Completion and delivery of the instrument may be delayed as spectrograph and instrument integration testing will not be completed as both activities require personnel to be in the laboratory.	The project is developing and implementing mitigation measures in coordination with LM and OU.
If: There is foreseen integration and testing technical issues, Then: Completion and delivery of the instrument may be delayed.	The project is developing and implementing mitigation measures in coordination with LM and OU.
If: Procurement acquisition delays access to space, Then: Completion and delay of the mission launch may occur.	The project is developing and implementing mitigation measures in coordination with program office and OU.

Acquisition Strategy

The acquisition strategy for GeoCarb leveraged OCO-2 and OCO-3 legacy instrument designs. The GeoCarb Spectrograph development was a competitive procurement. NASA will select spacecraft bus and launch vehicle in the near future.

GEOCARB

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Instrument	LM	San Francisco, CA
Spacecraft bus	TBD	TBD
Launch Vehicle	TBD	TBD

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Strategic Review Board (SRB)	Sept 2017	Systems Requirement Review (SRR)	Successful	Feb 2019
Performance	SRB	Feb 2019	Delta Preliminary Design Review (PDR)	Successful	Jan 2020
Performance	SRB	Jan 2020	Critical Design Review (CDR)	Successful	Oct 2024
Performance	SRB	Oct 2024	System Integration Review (SIR)	TBD	July 2025
Performance	SRB	July 2025	Operational Readiness Review (ORR)	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
ESSP Missions Research	18.0	17.8	**22.8**	26.8	26.8	29.8	30.5
Orbiting Carbon Observatory-3	7.0	7.6	**5.4**	0.0	0.0	0.0	0.0
OCO-2	9.9	11.4	**9.1**	10.7	10.7	10.7	10.7
GRACE	1.0	0.0	**0.0**	0.0	0.0	0.0	0.0
CloudSat	10.3	11.2	**9.0**	9.2	5.1	0.0	0.0
Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)	6.2	6.9	**6.9**	6.2	5.3	0.0	0.0
Total Budget	**52.5**	**54.9**	**53.3**	**52.9**	**47.8**	**40.5**	**41.2**
Change from FY 2022 Budget Request			**-1.6**				
Percent change from FY 2022 Budget Request			**-2.9%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Earth System Science Pathfinder (ESSP) Other Missions and Data Analysis projects include operating missions and mission-specific research. These innovative missions will enhance understanding of the current state of the Earth system and enable continual improvement in the prediction of future changes.

Mission Planning and Other Projects

ESSP MISSIONS RESEARCH

ESSP Missions Research provides funds for the science teams supporting ESSP operating missions. The science teams are comprised of competitively selected individual investigators who analyze data from the missions to address relevant science questions.

Recent Achievements

The GRACE-FO data revealed the extent of the 2021 United States Southwest drought, including the decline of the California Central Valley aquifer to levels on par with the record 2015/2016 drought. The U.S. Drought Monitor continues to routinely ingest the monthly and low-latency data to generate seasonal forecasts of groundwater and soil moisture for the contiguous United States, as well as weekly updates around the world.

An analysis of ice mass change over Antarctica found increased dynamic ice mass loss over Amundsen Sea Embayment and Bellingshausen Sea region. These processes are a major source of uncertainty for sea level change forecasts for the 21st century, and the GRACE/GRACE-FO observations are critical to inform and validate future simulations.

OTHER MISSIONS AND DATA ANALYSIS

Researchers examined the climatology of cloud phase over Southeast Asia using combined CloudSat–CALIPSO data. They found liquid-only clouds tend to occur in the relatively cold, dry, and stable lower troposphere. In contrast, clouds with ice appear more frequently in relatively warm, humid, and unstable conditions, and their seasonal distributions move with the Asian monsoon and the Intertropical Convergence Zone. Liquid clouds are found to be highly inhomogeneous, meaning not uniform, based on the heterogeneity index derived from Aqua Moderate Resolution Imaging Spectroradiometer, while ice-only and mixed-only clouds are often very smooth, indicating small variability. The measurement of "smoothness" or "not uniform" pertaining to liquid clouds points to changes in the atmosphere and water content in that area.

While Orbiting Carbon Observatory (OCO)-2 retrieves data in regularly repeating, narrow swaths, OCO-3 can perform multiple swaths over selected regions. A team of investigators are the first to describe results of the OCO-3 special sampling, snapshot-area maps (SAM) which are designed to collect detailed spatial information on carbon dioxide over regions on the scale of 50 miles by 50 miles. The SAMs highlight the carbon dioxide enhancements over Los Angeles, relative to desert regions to the northeast of the city. Typically, carbon dioxide enhancements are about 2 parts per million (ppm) in this region. Variations in the wind speed and direction largely explain variations in the magnitude and location of enhancements. The work also highlighted the fact that OCO-3 SAMs observes about three times the amount of emissions from the city as compared to the OCO-2 validation sampling over the region.

Advances in remote sensing have allowed for new means of detecting the role biological diversity plays in Earth system processes. For instance, using newly available evapotranspiration data from ECOSTRESS, researchers showed that plant species composition drives post-fire evapotranspiration patterns and is likely to continue to play critical roles in shaping post-fire plant communities and forest water cycling under future environmental change. Using newly available Global Ecosystem Dynamics Investigation (GEDI) Lidar data, studies revealed a strong relationship between canopy structure and tree diversity. This provides support for ecological theories that link structure to diversity via natural selection and environmental conditions. Scientists could apply these methods to assess tree diversity of any tropical forest. In preparation for future hyperspectral satellite missions (e.g., PACE), scientists showed that leaf spectra capture the phylogenetic history of seed plants and the evolutionary dynamics of leaf chemistry and structure. Consequently, spectra have the potential to provide breakthrough assessments of leaf evolution and plant phylogenetic diversity at global scales.

Currently, the ability to use remotely sensed soil moisture to investigate linkages between the water and energy cycles for use in data assimilation studies is limited to passive microwave data whose temporal revisit time is two to three days or active microwave products with a much longer (>10 days) revisit time. A recent study described a new soil moisture data product for the upper 5 centimeters of the soil surface derived from the Cyclone Global Navigation Satellite System (CYGNSS) constellation. The product is gridded to 36 km in sparsely sampled 6-hour intervals for +/− 38 degrees latitude from 2017–2020. Researchers developed the product by calibrating CYGNSS reflectivity observations to soil moisture retrievals from NASA's Soil Moisture Active Passive (SMAP) mission. They validated the retrievals against observations from 171 in-situ soil moisture probes, with a median error of 4.9 percent by volume. The new soil moisture product is complementary to SMAP, with a larger random noise component but more frequent observations.

Flood detection and the generation of flood maps play essential roles in policymaking, planning, and implementing flood management options. Investigators used CYGNSS data to retrieve flood maps over regions affected by recent flood in the southeastern part of Iran. The study used measurements over the Sistan and Baluchestan provinces acquired during torrential rain in January 2020. The study detected flooded areas based on a threshold test applied to the measured surface reflectivity. Researchers used images from Moderate-Resolution Imaging Spectroradiometer (MODIS) for evaluation of the results. The results successfully demonstrate that CYGNSS can produce short revisit time flood detection maps.

Two new investigations using the CYGNSS constellation demonstrated improvements in the estimation of maximum wind speeds in tropical cyclones (e.g., storm intensity). In the first investigation, scientists based the retrieval method on the production of a library of simulated CYGNSS observations using a synthetic storm model, as the parameters of the synthetic storm are varied. They used a matched filter approach between normalized simulated and measured observations to retrieve storm parameters. They used a case study to show results using the method for CYGNSS overpasses of Hurricane Irma. The maximum wind speed estimates have a retrieval mean difference of 4.52 m/s compared to reported National Hurricane Center Best Track forecasts. In the second investigation, scientists presented a new retrieval approach for obtaining wind speeds from CYGNSS observations. They used a variational technique based on the direct inversion of a physical forward model. Through comparisons with the background model and other spaceborne sensors (SMAP, SMOS, ASCAT-A/B), the study showed that this new approach has enhanced ability to infer wind speeds, including hurricane force winds.

Operating Missions

OCO-3

OCO-3, which launched in May 2019, is a complete stand-alone payload, built using the spare OCO-2 flight instrument, with additional elements added to accommodate installation and operation on the ISS. The OCO-3 instrument consists of three high-resolution grating spectrometers that collect space-based measurements of atmospheric carbon dioxide with the precision, resolution, and coverage needed to assess the spatial and temporal variability of carbon dioxide over an annual cycle.

Recent Achievements

The OCO-3 mission began delivering the first version of science data products to the public in January 2020, and delivery of an improved second version began in July 2021. The data products consist of atmospheric carbon dioxide measurements that are complementary to the OCO-2, spanning latitudes from 52 degrees N to 52 degrees S, with unique dense data collections over 50-mile by 50-mile regions. The second version of data greatly improved geolocation of the data products, especially for the 50-mile by 50-mile regional dataset collected over cities, volcanoes, and other sites of interest. The mission also provides a solar-induced chlorophyll fluorescence (SIF) data product. SIF is a measurement of photosynthesis activity, and an indicator of plant health. These data products are now serving the needs of scientists and researchers, as well as those in the science applications community.

An article published on OCO- showed how OCO-3 regional carbon dioxide measurements support the quantification and monitoring of anthropogenic CO2 emissions.

OCO-2

OCO-2 launched in July 2014 and collects precise carbon dioxide measurements across the globe every day from its vantage point in low-Earth orbit. Data scientists are gaining greater insight into how much carbon dioxide the Earth emits by natural sources and human activities, and the natural process for

OTHER MISSIONS AND DATA ANALYSIS

removing carbon dioxide from the atmosphere. This information may help decision-makers manage carbon dioxide emissions and reduce the human impact on the environment.

The OCO-2 instrument has collected almost one million daily soundings globally since September 2014. OCO-2 is currently in extended mission operations.

Recent Achievements

OCO-2 has created a high-quality record of the changes in the global distribution of carbon dioxide and SIF across seasons and through various global and regional climate changes such as El Niño and La Niña cycles. Scientists use the data to study the response of the natural carbon cycle to these changes, as well as extreme regional events including droughts, floods, and wildfires. On regional scales, these studies show that the land biospheric carbon dioxide sink is getting weaker across the tropics and moderately stronger at mid and high latitudes due to agricultural practices and climate change. OCO-2 observations also quantify carbon dioxide emissions from human activities including large power plants and urban centers. More recently, OCO-2 data captured changes in carbon dioxide concentrations during the COVID-19 pandemic as human activities decreased in response to regional and national lockdowns. Respected, peer reviewed journals continue to publish these science findings and contribute to national and international assessment studies. The continued nominal performance and operations of the spacecraft and instrument facilitated the long-term record of CO2 observations. The reliance on the Alaska facilities to downlink data from the observatory, which led to a systematic gap in OCO-2 measurements over the northern Pacific Ocean following a gyro failure resulting in operation constraints, has been greatly relieved by developing the capability to use a European ground station in Antarctica (the Troll Satellite Station) to downlink data on different orbits. Based on recommendations from the science team, the project has been developing and testing an improved OCO-2 data processing algorithm and will release an improved dataset for public distribution next year. The project continues to work closely with the OCO-3 project and the science community at large to maximize the scientific value of what is becoming a crucial climate data record of a fundamental driver of climate change.

CLOUDSAT

CloudSat, which launched in April 2006, measures cloud characteristics to increase understanding of the role of clouds in Earth's radiation budget. This mission provides estimates of the percentage of Earth's clouds that produce rain, provides vertically-resolved estimates of how much water and ice are in Earth's clouds, and estimates how efficiently the atmosphere produces rain from clouds. CloudSat collects information about the vertical structure of clouds and aerosols that other Earth-observing satellites do not collect. This data improves models and provides a better understanding of the human impact on the atmosphere.

CloudSat is currently in extended operations.

Recent Achievements

During the past year, other international and other Agency operational systems continued to adopt CloudSat observations. Now part of the European Centre for Medium Range Weather Forecasts forecast system, CloudSat shows positive impacts to both the analysis fit of other observations and to the subsequent forecast skill of the forecast system. The science community continues to use CloudSat data in formulating important improvements to the operational cloud layer height algorithms used by weather forecasters and derived from the Advanced Baseline Imager on the Geostationary Operational

Other Missions and Data Analysis

Environmental Satellites. CloudSat also provides critical verification data for global snowfall products produced by NASA's Global Precipitation Measurement (GPM) mission. The project exploits synergies with other NASA missions beyond GPM, as highlighted by the recently released cloud product that combines CALIPSO and the OCO-2 data with CloudSat.

During this past year CloudSat data served as the basis for identifying shortcomings in the projected higher climate warmings reported in the Intergovernmental Panel on Climate Change Sixth Assessment report (IPCC AR6). By using CloudSat observations of warm rain, studies point to how the misrepresentation of warm rain processes is a major source of error in low cloud feedback, which is responsible for producing high modelled climate sensitivities. When model warm rain processes are constrained to mimic CloudSat observations, projections are much lower than is reported in IPCC AR6. These examples demonstrate the continued wide utility of CloudSat to the applications and science communities. 3,500 peer-reviewed publications that cite the CloudSat data, including many references in the current IPCC assessment report, further highlight the value of CloudSat data.

Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO)

The CALIPSO mission, which launched in April 2006, provides the first comprehensive three-dimensional measurement record of aerosols, helping to better understand how aerosols form, evolve, and transport over the globe. The mission provides data on the vertical structure of clouds, and the geographic and vertical distribution of aerosols, and further detects sub-visible clouds in the upper troposphere. CALIPSO also indirectly estimates the contribution of clouds and aerosols to atmospheric temperature.

CALIPSO is currently in extended operations.

Recent Achievements

CALIPSO continues to provide unique vertical profile observations of clouds and atmospheric particle (aerosol) layers over the globe. During FY 2021, the mission released a new imaging infrared radiometer data product that provided a unique climatology of the occurrence and properties of cirrus clouds over the globe. These observations combined with the CALIPSO lidar measurements helped advance knowledge on how clouds impact the Earth's energy balance. The team matured several major improvements to the CALIPSO data products to address specific needs by the scientific community, which will be featured in two data releases in 2022. In addition, the team initiated the formation of an international group of researchers that seeks to enhance the exchange of information on aerosols among modeling and instrument teams around the world. This effort will increase understanding on aerosols that will lead to improved forecast predictions for air quality and climate.

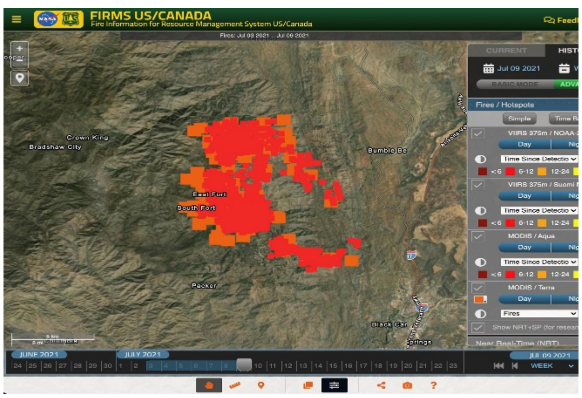
EARTH SCIENCE DATA SYSTEMS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**299.6**	**344.4**	**366.1**	**406.7**	**383.9**	**399.1**	**414.8**
Change from FY 2022 Budget Request			**21.7**				
Percent change from FY 2022 Budget Request			**6.3%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



Shown above is a visualization of active fire detection data in the context of a current perimeter for a wildland fire. FIRMS United States/Canada is a joint effort by NASA and the USDA FOREST SERVICE to provide access to low latency satellite imagery and science data products from EARTH OBSERVATION SYSTEM (EOS) satellite assets to identify the location, extent and intensity of wildfire activity and its effects.

The Earth Science Data Systems (ESDS) program oversees the life cycle of Earth science data with the principal goal of maximizing the scientific return from NASA's missions and experiments for research and applied scientists, decision makers, and the nation.

The ESDS program acquires, processes, preserves, and distributes observational Earth science data from spacecraft, aircraft, and in-situ sensors to support Earth Science research focus areas. The ESDS program primarily accomplishes this via the Earth Observing System Data and Information System (EOSDIS), which has been in operation since 1994.

EOSDIS has continuously evolved to take advantage of improved technology to meet the increasing demands of data providers and users. NASA expects the EOSDIS data archives to grow from over 59 Petabytes in 2021 to 230 Petabytes in 2025. This includes the addition of several new missions while supporting ongoing operations.

The program continuously evolves its capabilities by communicating with users, adopting new technologies, and supporting vibrant competitive research elements within the Data System Evolution (DSE) element of the program. These activities help prioritize data system investments to more efficiently manage user needs and identify technologies to improve the processing, preservation, and access to the diverse data NASA collects.

Growth in both the data ingest rate, as well as overall archive volume poses challenges for archiving, distribution, and analysis of the data. To address these challenges, the ESDS program initiated a mission processing study to identify and assess data system architectures that can meet mission science processing objectives, enable data system efficiencies, promote open science principles, and seek opportunities that support Earth system science.

EARTH SCIENCE DATA SYSTEMS

The ESDS program also contains the Commercial SmallSat Data Acquisition project, which is responsible for identifying, evaluating, and acquiring data from commercial sources that support NASA's Earth science research and application goals.

It also contains the Open Source Science project which is coordinating and implementing open science capabilities for all SMD.

NASA's Earth Science data is available to the public at https://earthdata.nasa.gov.

EXPLANATION OF MAJOR CHANGES IN FY 2023

The FY 2023 budget request includes an additional $20 million to develop satellite data products that are responsive to civil agency satellite needs identified in the 2020 assessment process of the interagency U.S. Group on Earth Observations Satellite Needs Working Group (SNWG), and to develop a SNWG Management Office to ensure reliable needs assessment support and implementation of NASA's response to the U.S. Group on Earth Observations biennial survey of Federal agency satellite data needs.

As part of a renewed emphasis on providing actionable data and information to a broad range of users, NASA is planning an Earth Information Center with an initial focus on prototyping capabilities for a greenhouse gas monitoring and information system that will integrate data from a variety of sources with a goal of making data more accessible and usable to Federal, state, and local governments, researchers, the public, and other users. These efforts will be implemented in coordination with other agencies and partners. An additional $5 million is included in the Data Systems Evolution project to support these efforts. A complementary $3 million investment in the Applied Sciences program will support user applications of greenhouse gas data.

ACHIEVEMENTS IN FY 2021

The EOSDIS archives grew to over 59 petabytes in FY 2021 and it distributed nearly 2 billion data products to more than 5 million users around the world. The program provided data stewardship to over 14,300 unique data products from more than 120 instruments. It also released over 800 new datasets from new and continuing missions totaling 10PB for public access that is available in Earthdata Cloud, a commercial cloud application. The program allowed users to search over 53,000 data collections in the Common Metadata Repository, with 98 percent of queries completing in less than 1 second. The Common Metadata Repository has grown to manage over 860 million files of sensor data from Earth science missions.

ESDS continued the development of a commercial cloud environment (Earthdata Cloud) to meet the needs of future high data volume missions such as SWOT and NISAR, as well as to provide data management and user access for many ongoing Earth science missions.

The Global Imagery Browse System (GIBS) began migrating ingest, archive, and web services to the Earthdata Cloud, all of which are transparent to end users and imagery providers.

The NASA Sentinel Gateway continued to serve data from the European Space Agency (ESA) partnership, delivering 55 terabytes of data per week from ESA to the Distributed Active Archive Centers (DAACs). The total archive of Sentinel data is now over 14 petabytes. During FY 2021, NASA distributed over 15 million files of data (more than 26 petabytes) from ESA's Sentinel 1-A/B, 3A/B, 5-P missions in support of NASA science activities. ESDS supported over 800 unique near-real-time datasets

EARTH SCIENCE DATA SYSTEMS

in the Land, Atmosphere Near real-time Capability for EOS (LANCE) system. LANCE produces over 44 terabytes of data per week within 3 hours of satellite acquisition.

The Commercial SmallSat Data Acquisition (CSDA) project successfully uplifted data licenses for multiple vendors, allowing access to all Federal researchers and not only NASA users. Due to the uplift of licenses, the CSDA program supported the increase of eligible users with new account creation, verification, data access, and distribution. The project awarded several activities to study the Earth system using already purchased commercial data and established an evaluation team to formally assess new commercial data for scientific research and application.

The IMPACT team continued to evolve the NASA COVID-19 dashboard into a broader storytelling platform, while continuing to collaborate with JAXA and ESA on the global Earth Observatory (EO) Dashboard effort. In June 2021, a global EO Dashboard hackathon included 4,432 participants, 508 teams, and 245 projects.

The NASA Citizen Science for Earth Systems program element sought efforts for gathering new data to enhance existing data holdings and activities focusing on reuse, enhancement, or characterization of existing NASA Citizen Science Data.

In May 2021, the Open Source Science team held a three-day virtual workshop comprised of invited experts, both internal and external to NASA, to surface insight and strategic guidelines for NASA on the application of Artificial Intelligence to science. The outcomes of this workshop provided guidelines and recommendations for the future of AI research and applications within NASA.

Advanced Concepts executed by IMPACT included the Harmonized Landsat Sentinel-2 (HLS) data products made available for public access by the Land Processes Distributed Active Archive Center (LP DAAC) in August 2021. The release of science quality products supports NASA and several other Federal agencies in tracking agricultural and vegetation health, and other land surface monitoring applications.

The Multi-Mission Algorithm and Analysis Platform (MAAP) data team at IMPACT had the first production release of its virtual research environment for the processing, analysis, and sharing of data and development and sharing of algorithms. This platform will be used to develop above ground biomass products for United Nations Framework Convention on Climate Change (UNFCCC)'s first 'Global Stocktake' (GST), which will take place in 2023.

WORK IN PROGRESS IN FY 2022

Several new missions will provide data in FY 2022, including TROPICs, EMIT on ISS, and several suborbital missions. ESDS is continuing to focus on open-source cloud-native software to provide user services on data, including the ability to subset and subsample. The program will develop and enable cloud-optimized formats and standardized tools that will work across data stored in the Earthdata Cloud. The new on-premise backup system for datasets originating in the cloud will begin operations starting with the SWOT mission. Additionally, the program will continue to migrate high value datasets into the Earthdata Cloud in priority order.

With the announcement of the Earth System Observatory (ESO), the ESDS program has engaged early with the missions to identify and assess potential architectures that can meet the ESO mission science processing objectives, enable data system efficiencies, promote open science principles, and seek opportunities that support Earth system science. Two studies focused on ways to reduce the latency of

EARTH SCIENCE DATA SYSTEMS

science data and streamline science data processing, accelerating science returns from the system as a whole.

ESDS is continuing development on a software framework that serves as a common interface to assist data producers, such as flight projects, instrument teams, science teams, and DAACS, in the management of various data publication processes, including legacy airborne datasets.

The team will generate historical HLS data products and continue forward processing to support land monitoring applications research and further refine and develop new capabilities for the data system to support the release of the MAAP to a broader user community in October 2022. The APT team will complete enhancements to the authoring user interface and will transition the tool to a standard NASA ESDIS data publication workflow and provide community user support.

NASA will continue development on the Earth Observation dashboard in collaboration with JAXA and ESA as a storytelling platform to demonstrate environmental change.

Open Source Software (OSS) began in FY 2021 and has already initiated activities to establish an open science ecosystem. Initial requirements for an SMD-wide information catalog are progressing, which will inform the development of a pilot catalog in early FY 2022. NASA released two Research Opportunities in Space and Earth Science (ROSES) announcements to support widely used open source scientific software and formed a machine learning working group.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

The program will expand its capabilities to support data from new missions, including data from SWOT, JPSS-2, and TEMPO. The program also grew with the addition of the first ESO mission, NISAR. NISAR plans to produce over 27 petabytes of data per year. The Common Metadata Repository will continue to expand and become more flexible in FY 2023 and the ESDS will continue to see its adoption by other agencies.

NASA will plan for an Earth Information Center with an initial focus on prototyping capabilities for a greenhouse gas monitoring and information system that will integrate data from a variety of sources with a goal of making data more accessible and usable to Federal, state, and local governments, researchers, the public, and other users. These efforts will be implemented in coordination with other agencies and partners.

Advancing Collaborative Connections for Earth System Science (ACCESS) will infuse appropriate activities into the operational system.

The CSDA project will work to greatly expand the Agency's investment and provide data access for research and application with more permissive licenses, including commercial climate data, using standard end user license agreements. The project will also seek opportunities to expand the user base and maximize their use. OSS will deploy a pilot version of the SMD information catalog and will initiate a data science internship program to support students in related science fields, with a particular focus on historically excluded populations.

IMPACT will release the Earth Observation dashboard for environmental change with interactive data and stories.

The SNWG Management Office will coordinate and manage the formulation and implementation of the highest priority satellite data products from the 2020 assessment process of the U.S. Group on Earth

EARTH SCIENCE DATA SYSTEMS

Observations Satellite Needs Working Group. The office will establish formal agreements and manage development and operational activities to provide solutions and engage SNWG Federal and scientific end-users throughout the lifecycle of each solution. Examples of SNWG activities include: precision air quality forecasts for U.S. Embassies experiencing significant air quality issues via new sensors distributed internationally in collaboration with the U.S. State Department; building upon the 2016 Harmonized Landsat Sentinel-2 (HLS) activity to immediately create a suite of vegetation indices generated for the HLS archive of record and going forward to reduce duplicative processing efforts across the U.S. Government; combining hyperspectral sounder data with GNSS-RO (Spire) commercial data into merged global science products that improve understanding and modeling of Planetary Boundary Layer (PBL) processes for weather forecasting applications; and supporting the NASA data systems that ingest, archive, and distribute all SNWG solutions' data products.

Additionally, ESDS will continue developing new data system capabilities for the MAAP and making critical data available for use within the platform and supporting user needs, and work as a liaison to support Machine Learning adoption. The team will also develop generalizable Machine Learning pipelines for rapid prototyping of science problems.

Program Elements

EARTH SCIENCE DATA AND INFORMATION SYSTEM (ESDIS)

The ESDIS project manages the geographically distributed science systems of EOSDIS including the DAACs, Science Investigator-led Processing Systems (SIPS), the Land, Atmosphere Near real-time Capability for the Earth Observing System (LANCE), and core systems. Together, these systems support the processing of satellite data and seamless interdisciplinary access to EOSDIS data, including data products, data services, and data handling tools for a broad range of user communities that include scientists, Government agencies, commercial users, and the public.

- SIPS generate high-quality science products from Terra, Aqua, Aura, S-NPP, and JPSS missions at facilities under the direct control of the instrument principal investigators and team leaders. Products produced at SIPS undergo extensive quality assurance before the program transfers them to DAACs for archiving and distribution to users.
- DAACs archive, document, and distribute data and provide user support for NASA's past and current Earth-observing satellites, Sentinel 1, 3, 5P, and 6 satellites, airborne investigations, and field measurement programs. Acting in concert, the DAACs provide reliable, robust services to users whose needs may cross the traditional boundaries of a science discipline, while continuing to support the unique needs of users within specific science discipline communities. The DAAC facilities, hosted at NASA or other institutions, each specialize in a science discipline such as atmosphere, calibrated radiance, solar radiance, cryosphere, human dimensions, land, or ocean science.
- LANCE generates and provides access to near real-time products from the Atmospheric Infrared Sounder, Advanced Microwave Scanning Radiometer 2, Microwave Limb Sounder, Moderate Resolution Imaging Spectroradiometer, Measurement of Pollution in the Troposphere, Ozone Monitoring Instrument, Ozone Mapping Profiler Suite, and Visible Infrared Imaging Radiometer Suite (VIIRS) (VIIRS-Land and VIIRS Atmosphere) instruments in less than three hours from the

EARTH SCIENCE DATA SYSTEMS

time of observation. The data support NASA applications users who are interested in monitoring and analyzing a wide variety of natural and man-made phenomena.

The EOSDIS system supports several core systems to provide a common entry point to discover access and visualize data from the distributed DAACs and SIPS. The program developed core systems to reduce duplication and improve user access to EOSDIS data, including:

- Common Metadata Repository (CMR) is a high-performance, high-quality, continuously evolving metadata system that catalogs all data and service metadata records for EOSDIS and is the authoritative management system for all EOSDIS metadata.
- Global Imagery Browse Services (GIBS) provides visual representations of NASA Earth science data at full resolution in a free, open, and interoperable manner; Through responsive and highly available web services, it enables interactive exploration of data to support a wide range of applications including scientific research, applied sciences, natural hazard monitoring, and outreach. GIBS provides much of the LANCE near real-time imagery, as well as present-day and historical imagery.
- NASA-compliant General Application Platform is a cloud-based platform that provides a scalable and flexible application platform solution that offers the cost benefits of hardware consolidation with the safety and security of application sandboxing and resource management.
- Cumulus is a cloud optimized software package for performing Earth science data ingest, archive, and distribution capabilities to support all EOSDIS missions.
- Earth Observing System Networks provide effective access to EOSDIS. They depend on end-to-end network connectivity between users and geographically distributed DAACs. The NASA Earthdata website integrates information from across EOSDIS. Earthdata is the entry point for EOSDIS data, articles, documentation, and collaboration. It leverages CMR to provide comprehensive search capabilities. Earthdata offers new and experienced users an organized view of EOSDIS resources and the latest events.
- The NASA Sentinel Gateway transfers data from a dedicated interface to the European Commission's Copernicus Programme Sentinel 1, 3, and 5P satellite ground system. The Sentinel Gateway transfers data from the Sentinel satellites to DAACs for archival and distribution to users.
- For more information, see https://earthdata.nasa.gov

DATA SYSTEM EVOLUTION (DSE)

The Data System Evolution project funds various research opportunities, as well as interagency initiatives and promotion of data and service interoperability through the development and implementation of standards. DSE is composed of two competitive components: Advancing Collaborative Connections for Earth System Science (ACCESS), and Citizen Science for Earth Systems Program (CSESP). DSE also supports the Interagency Implementation and Advanced Concepts Team (IMPACT) activity and the development of long-term data records needed by NASA scientists.

- ACCESS supports the evolution of ESDIS by investing in technology to enhance the analysis, delivery, and preservation of Earth science data. NASA solicits proposals in this competitive program element every two years. The intent is to identify and develop promising technology prototypes into operational tools to infuse into the EOSDIS.

EARTH SCIENCE DATA SYSTEMS

- CSESP consists of two elements: The collection and analysis of data by citizen scientists across all Earth Science focus areas, and technological development and production of low-cost sensors for measurement and monitoring. NASA solicits proposals in this competitive program element every three years.
- IMPACT works with other Government agencies to increase the use of NASA Earth observations. This team assesses, independently evaluates, and makes recommendations to improve EOSDIS services and processes; manages archiving of airborne science observations; and develops proof of concept data system capabilities. IMPACT works closely with the SNWG to design and implement a systematic plan to assist other agencies in incorporating NASA Earth observation data into their workflows.

NASA will design and begin to implement a common system to host greenhouse gas monitoring measurements from a variety of data sources.

DSE activities also support the widespread use of NASA Earth science observations through the development and implementation of standards, through collaborations with other space agencies, and by leading activities to improve the discoverability of NASA data within https://www.Geoplatform.gov.

OPEN SOURCE SCIENCE

The Open Source Science project (OSS) is a project built on concepts from Open-Source Software, expanding participation in developing code, applied to the scientific process to accelerate discovery by openly conducting science from project initiation through implementation. OSS is a cross divisional effort with ESDS leading several foundational activities. The primary goal is to create an Open Science Ecosystem to dramatically accelerate scientific discovery and to expand access to scientific knowledge produced by NASA by achieving the goals described in the "Strategy for Data Management and Computing for Groundbreaking Science 2019-2024." The major elements of the strategy are:

- Develop and Implement Capabilities to Enable Open Science;
- Engage the SMD science community in the evolution of data systems; and
- Harness the Community and Strategic Partnerships for Innovation.

NASA will use new investments for OSS targeted toward developing a SMD-wide open science ecosystem. The ecosystem will invest in and scale existing Divisional capabilities for cross-SMD use and developing new capabilities through targeted funding. OSS is comprised of, in several foundational activities needed for the open science ecosystem and advancing data science. These activities include:

- Development of a SMD-wide data catalog to support cross-Divisional discovery of scientific data, based on ESDS Common Metadata Repository;
- Provision of cross-divisional discovery tools for scientific publications that link directly to the data;
- Improved access to the tools and data needed to empower scientists;
- Investments in the maintenance of critical open source software, toolkits, and libraries used by NASA scientists and developers;
- Capacity building to transform the NASA scientific community to use Open Science principles to accelerate discovery;
- An AI/ML SMD study and demonstration team; and

EARTH SCIENCE DATA SYSTEMS

- The use of data science prizes and challenges to leverage the skills and expertise of the community to develop innovative solutions.

COMMERCIAL SMALLSAT DATA ACQUISITION

The Commercial SmallSat Data Acquisition (CSDA) project (previously known as the Small Satellite Constellation Initiative) identifies, evaluates, and acquires data from commercial sources to support NASA's Earth science research and applications activities. This will provide a cost-effective way to augment and/or complement the suite of Earth observations acquired by NASA and other Government agencies, as well as those acquired by international partners. NASA will emphasize data acquired by small-satellite constellations, affording the means of complementing NASA acquired data with higher resolutions, increased temporal frequency, or other novel capabilities in support of existing Earth science and application activities.

NASA-funded researchers examine and analyze the data to determine the utility of the commercial data products. CSDA provides an opportunity for vendors with new or significantly enhanced capabilities to have their data evaluated by NASA for longer-term procurement.

MAKING EARTH SYSTEM DATA RECORDS FOR USE IN RESEARCH ENVIRONMENTS (MEASURES)

The overall objective of MEaSUREs is to provide Earth science higher-level data products and services driven by NASA's Earth science goals. These data products, called Earth Science Data Records, are critical for understanding Earth System processes; assessing variability, long-term trends, and changes in the Earth System; and providing input and validation means to modeling efforts. MEaSUREs is a competitive program element solicited every five years.

MEaSUREs emphasizes linking together multiple satellites into a constellation, developing the means of utilizing a multitude of data sources to form a coherent time series, and facilitating the use of NASA's extensive data in the development of comprehensive Earth system models. In addition, MEaSUREs activities include infusion or deployment of applicable science tools that contribute to data product quality improvement, consistency, merging or fusion, or understanding.

PROGRAM SCHEDULE

The ESDS program solicits research opportunities approximately every three years for ACCESS, and every three years for Citizen Science for Earth System Science in Data Systems Evolution, and every five years for MEaSUREs. The ESDIS project continuously delivers software to improve functionality and improve efficiency. The OSS project will solicit opportunities each year to support its objectives. The CSDA project provides on-ramp opportunities for new vendors every 18-24 months.

Date	Significant Event
Q2 FY 2022	ROSES MEaSUREs Solicitation Released ROSES OSSI Solicitation Released CSDA On-Ramp Released 4

EARTH SCIENCE DATA SYSTEMS

Date	Significant Event
Q1 FY 2023	ROSES ACCESS Solicitation Released
Q1 FY 2023	CSDA Program RFI Released
Q2 FY 2023	ROSES OSSI Solicitation Released
Q2 FY 2023	OSSI Year of Open Science
Q1 FY 2024	CSDA Program RFI Released
Q2 FY 2024	ROSES CSESP Solicitation Released
Q2 FY 2024	ROSES OSSI Solicitation Released
Q1 FY 2025	ROSES ACCESS Solicitation Released
Q1 FY 2025	CSDA Program RFI Released
Q2 FY 2025	ROSES OSSI Solicitation Released
Q1 FY 2026	ROSES CSESP Solicitation Released
Q1 FY 2026	CSDA Program RFI Released
Q2 FY 2026	ROSES OSSI Solicitation Released
Q1 FY 2027	ROSES ACCESS Solicitation Released
Q2 FY 2027	ROSES MEaSUREs Solicitation Released

Program Management & Commitments

The Earth Systematic Missions program at Goddard Space Flight Center (GSFC) provides program management for the ESDIS project. NASA Headquarters manages the Commercial SmallSat Data Acquisition, DSE and MEaSUREs projects.

Program Element	Provider
EOSDIS core system	Provider: Various Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A
Alaska Synthetic Aperture Radar Facility Distributed Active Archive Center (DAAC) (Fairbanks, AK)	Provider: University of Alaska Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A
Atmospheric Science Data Center (Hampton, VA)	Provider: LaRC Lead Center: LaRC Performing Center(s): LaRC Cost Share Partner(s): N/A

EARTH SCIENCE DATA SYSTEMS

Program Element	Provider
Goddard Earth Science Data and Information System Center (Greenbelt, MD)	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A
Land Processes Data Center (Sioux Falls, SD)	Provider: USGS Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A
National Snow and Ice Data Center (NSIDS; Boulder, CO)	Provider: University of Colorado Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A
Oak Ridge National Laboratory DAAC (Oak Ridge, TN)	Provider: Oak Ridge National Laboratory Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A
Physical Oceanography DAAC (Pasadena, CA)	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A
Socio-economic Data and Applications Center (SEDAC; Palisades, NY)	Provider: Columbia University Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A
Crustal Dynamics Data Information System (Greenbelt, MD)	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A
Global Hydrology Research Center (Huntsville, AL)	Provider: University of Alabama Lead Center: MSFC Performing Center(s): MSFC Cost Share Partner(s): N/A
Interagency Implementation and Advance Concepts Team (Huntsville, AL)	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC Cost Share Partner(s): N/A

EARTH SCIENCE DATA SYSTEMS

Acquisition Strategy

Research opportunities within DSE are available through NASA's ROSES announcements. NASA competitively selects ESDIS support contracts through full and open competition.

NASA initiates Commercial SmallSat data acquisitions via SAM.gov. After a favorable evaluation, if deemed of sufficient value, the Agency purchases them for broader sustained use. The program will select contract types on a vendor-by-vendor basis, selecting those best suited to provide long-term access to data.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
EOSDIS Evolution & Development	Raytheon	Riverdale, MD
National Snow and Ice Data Center (NSIDC)	University of Colorado	Boulder, CO
Alaska SAR Facility	University of Alaska	Fairbanks, AK
SEDAC	Columbia University	Palisades, NY
Commercial SmallSat Data	BlackSky Technology Inc	Herndon, VA
Commercial SmallSat Data	Airbus Defense and Space Inc.	Herndon, VA
Commercial SmallSat Data	Teledyne Brown Engineering	Huntsville, AL
Commercial SmallSat Data	Maxar Technologies	Westminster, CO
Commercial SmallSat Data	Planet Labs	San Francisco, CA

INDEPENDENT REVIEWS

The American Customer Satisfaction Index measures customer satisfaction with the NASA Earth Observing System Data and Information System (EOSDIS) at a national level for each Distributed Active Archive Center (DAAC) on an annual basis. The average aggregate Customer Satisfaction Index score for NASA EOSDIS over the last 11 years is 77. It also identifies the key areas that NASA can leverage across the DAACs to continuously improve its service to its customers.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	American Customer Satisfaction Index	2021	Survey current EOSDIS users to assess satisfaction with current services	Customer Satisfaction Index: 81	2022

EARTH SCIENCE TECHNOLOGY

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**83.7**	**91.1**	**102.3**	**105.9**	**114.1**	**117.7**	**119.0**
Change from FY 2022 Budget Request			**11.2**				
Percent change from FY 2022 Budget Request			**12.3%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The TEMPEST-D CubeSat is pictured above shortly after being deployed into low-Earth orbit (LEO) from the International Space Station (ISS) on July 13, 2018. Slightly larger than the average shoebox, the TEMPEST-D mission lasted for nearly three years (de-orbited in June 2021) and paved the way for a future constellation of compact microwave sensors that could improve the temporal resolution of weather and climate data.

Advanced technology plays a major role in enabling Earth science research and applications. The Earth Science Technology Program enables previously infeasible science investigations, improves existing measurement capabilities, and reduces the cost, risk, and/or development times for Earth science instruments and information systems.

EXPLANATION OF MAJOR CHANGES IN FY 2023

This budget request initiates the Technology Development for Support of Wildfire Science and Disaster Risk Mitigation (FireTech) activity and accelerates the development of next-generation space-based Greenhouse Gas (GHG) measurements and information system approaches.

ACHIEVEMENTS IN FY 2021

The Program worked on 136 active projects in FY 2021. Within the portfolio of projects, 39 percent advanced at least one Technology Readiness Level (TRL) during FY 2021 and at least 8 projects advanced more than one TRL. Historically, student participation in Earth Science Technology Office projects has been substantial, with a cumulative total of at least 1,017 students from 161 institutions participating in the program. In FY 2021, 104 students from 44 institutions were involved in the program.

EARTH SCIENCE TECHNOLOGY

The program infused several projects into science measurements, airborne campaigns, data systems, or other follow-on activities during the year. For example, the Ultra-Wideband Software Defined Microwave Radiometer (UWBRAD) instrument developed under the 2013 Instrument Incubator Program solicitation was deployed with support from the National Science Foundation as part of the international Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) expedition. MOSAiC investigated the Arctic processes and evolution of ocean-ice-atmosphere system in the polar region.

Another example is the Ecological Spectral Model Library (EcoSML), one of several tools developed under the Ecological Spectral Information System, a 2016 Advanced Information Systems Technology project. Now included in GitHub, EcoSML enables researchers to share models and facilitates the use of spectral data over a larger scientific community.

In a cross-divisional example, NASA's Heliophysics Science Division selected the Electrojet Zeeman Imaging Explorer (EZIE) mission in early FY 2021 to explore electric currents in Earth's atmosphere that link the aurora to the magnetosphere. Led by the Johns Hopkins Applied Physics Lab, EZIE will include three CubeSats, flying in formation and carrying payloads containing of millimeter radiometers with high-resolution digital spectrometers. These payloads include substantial heritage from technologies originally developed through the Earth Science Technology Office (ESTO), including:

- Analog front ends derived directly from the TEMPEST-D (TEMPoral Experiment for Storms and Tropical Systems–Demonstration) CubeSat;
- Digital back ends developed for use on the CubeRRT (CubeSat Radio Frequency Interference Radiometer Technology) CubeSat; and
- Overall digital design is based on early work on an Agile Digital Detector, through a 2004 award under the Instrument Incubator Program that has enjoyed widespread infusion, including the Hurricane Imaging Radiometer (HIRAD) airborne instrument.

WORK IN PROGRESS IN FY 2022

With guidance from the 2017 Earth Science Decadal Survey and longer-term technology development strategies, the program plans to award funding for several new cohorts of technology projects. The Instrument Incubator Program (IIP), Advanced Information Systems Technology (AIST), and Decadal Survey Incubation (DSI) program elements all released solicitations in FY 2021 and expect to award. Project selections will be in early-to-mid FY 2022. The DSI solicitation will seek technologies to address needs for the Planetary Boundary Layer and Surface Topography and Vegetation targeted observable areas.

The program also plans to solicit, proposals for the Advanced Component Technology (ACT) program element as well as a new wildfire technology development effort related to the miniaturization of smart sensors that could fly on Uncrewed Aerial Vehicles (UAVs) or small aircraft to benefit wildfire resource management. Existing program elements will continue to support UAS-based wildfire observation needs. NASA expects to award both program elements in early FY 2023.

The program has several activities planned for accelerating technology developments and demonstrations supporting climate variability and climate change science. NASA expects three CubeSat developments to advance to launch in FY 2022: the two NanoSat Atmospheric Chemistry Hyperspectral Observation System CubeSats (NACHOS-1 and NACHOS-2), and the Compact Total Irradiance Monitor (CTIM) flight demonstration.

EARTH SCIENCE TECHNOLOGY

The program also plans to jumpstart a digital twin Earth prototype framework leveraging several AIST projects. The digital twin Earth prototype will mirror a localized Earth science system of an urban area and utilize the combination of data analytics, machine learning, and state-of-the-art models to conduct "what if" investigations that can result in actionable predictions and relate natural and physical events to urban development and human activities.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

In FY 2023, the program plans to select awards under the Sustainable Land Imaging – Technology (SLI-T), Advanced Component Technologies (ACT), and Wildfire Technology program elements. At the beginning of FY 2023, ESTO is starting a new activity, the Technology Development for Support of Wildfire Science and Disaster Risk Mitigation (FireTech), to introduce new, innovative Earth system observation and analysis capabilities to improve prediction and management of wildfires and their impacts. The FireTech program will solicit ideas that span observation and information system technologies. The program plans to release a competitive solicitation under the AIST program element. ESTO will also initiate funding for new focused activity emphasizing the use of competitive approaches to advance the development and/or testing of new technological approaches for space-based GHG measurement.

Program Elements

ADVANCED TECHNOLOGY INITIATIVES (ATI)

This project enables development of critical component and subsystem technologies for instruments and platforms, mostly in support of the Earth Science Decadal Survey. Current awards focus on areas such as space-qualified laser transmitters, passive optical technologies, and microwave and calibration technologies. Other awards support measurements of solar radiance, ozone, aerosols, and atmospheric gas columns for air quality and ocean color, and for coastal ecosystem health and climate emissions.

The InVEST program element selects new technologies to validate in space prior to use in a science mission. This is necessary because the space environment imposes stringent conditions on components and systems, some of which cannot be tested on the ground or in airborne systems. Validation of Earth science technologies in space will further reduce the risk of new technologies in future Earth Science missions.

INSTRUMENT INCUBATOR

This project develops instruments, instrument concepts, and measurement techniques at the system level, including laboratory breadboards and operational prototypes that often lead to ground or airborne demonstrations. NASA currently funds 30 Instrument Incubator efforts. These instrument prototypes support multiple measurements including carbon dioxide, carbon monoxide, ocean color, and solar spectrum (from ultraviolet to infrared) for Earth science. Instrument Incubator supports the development of instrument design and prototyping through laboratory and/or airborne demonstrations for innovative measurement techniques that have the highest potential to meet the measurement capability requirements of the NASA Earth science community in both the optical and the microwave spectrum.

EARTH SCIENCE TECHNOLOGY

DECADAL INCUBATION

NASA created this project in response to the recommendation of the 2017 Earth Science Decadal Survey. It focuses on maturing observing systems, instruments, technologies, and measurement concepts to address high priority science for the next decade (2027 – 2037) in two targeted observable areas. These observable areas are the Planetary Boundary Layer and Surface Topography and Vegetation. Anticipated developments in this project include various observation and information system technologies, modeling/system design, analysis activities, and small-scale pilot demonstrations in support of the two observable areas.

ADVANCED INFORMATION SYSTEMS TECHNOLOGY (AIST)

This project develops end-to-end information technologies that enable new Earth observation measurements and information products. The technologies help process, archive, access, visualize, communicate, and understand Earth science data. Currently, AIST activities focus on three primary areas of need to support future Earth system science measurements:

- Analytic Center Framework (ACF): ACF technology projects aim to harmonize tools, data, and computing environments to meet the needs of Earth science investigations of physical processes and natural phenomena. These investigations integrate new or previously unlinked datasets, tools, models, and a variety of computing resources together into a common platform to address previously intractable scientific questions. Additionally, these projects generalize custom or unique tools to make them accessible and useful to a broader community.
- New Observing Strategies (NOS): NOS projects dynamically coordinate and collaborate observations across multiple platforms (space, air, ground) to acquire a more complete picture of Earth Science phenomena. NOS can be described as a federated Observing System, a generalized SensorWeb, or more generally as an "Internet-of-Space (IoS)" concept in which each node can be an individual sensor, a group of sensors, a constellation of satellites (e.g., Earth System Observatory concept), a model or integrated models, or even database(s) or any other source of relevant information, that have varying degrees of coordination to achieve a common science objective.
- Earth System Digital Twin (ESDT): An ESDT is an interactive and integrated multidomain, multiscale, digital replica of the state and temporal evolution of Earth systems. The ESDT thrust will develop capabilities toward the development of future digital twins of the Earth or of subcomponents of the Earth, as well as toward the development of an overarching framework that will continuously evolve and connect the various components developed by Research and Analysis, Applied Sciences, Data Systems, and Computational Capabilities from other Earth Science Programs.

Program Schedule

Date	Significant Event
Q1 FY 2022	ROSES-2021 selection no earlier than six months of receipt of proposals
Q2 FY 2022	ROSES-2022 solicitation
Q1 FY 2023	ROSES-2022 selection no earlier than six months of receipt of proposals

EARTH SCIENCE TECHNOLOGY

Date	Significant Event
Q2 FY 2023	ROSES-2023 solicitation
Q1 FY 2024	ROSES-2023 selection no earlier than six months of receipt of proposals
Q2 FY 2024	ROSES-2024 solicitation
Q1 FY 2025	ROSES-2024 selection no earlier than six months of receipt of proposals
Q2 FY 2025	ROSES-2025 solicitation
Q1 FY 2026	ROSES-2025 selection no earlier than six months of receipt of proposals
Q2 FY 2026	ROSES-2026 solicitation
Q1 FY 2027	ROSES-2026 selection no earlier than six months of receipt of proposals
Q2 FY 2027	ROSES-2027 solicitation

Program Management & Commitments

Program Element	Provider
Instrument Incubator	Provider: Various Lead Center: HQ Performing Center(s): GSFC, JPL, LaRC, MSFC, AFRC Cost Share Partner(s): N/A
Advanced Information Systems	Provider: Various Lead Center: HQ Performing Center(s): GSFC, JPL, LaRC, MSFC, ARC, JSC Cost Share Partner(s): N/A
Advanced Technology Initiatives	Provider: Various Lead Center: HQ Performing Center(s): GSFC, JPL, LaRC Cost Share Partner(s): N/A
Decadal Incubation	Provider: Various Lead Center: HQ Performing Center(s): GSFC, LaRC, JPL Cost Share Partner(s): N/A

Acquisition Strategy

NASA primarily procures tasks through full and open competition, such as through the ROSES announcements. The solicitation of technology investments is competitive and selected from NASA centers, industry, and academia as well as other Government agencies, Federally Funded Research and Development Centers, and nonprofit organizations.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	National Academies of Science, Committee on Earth Science, and Applications from Space (CESAS)	Nov 2021	Provide results of the Earth Science Technology Program and outline program's ongoing response to 2017 Decadal Survey	CESAS was pleased with the current status of the program	Nov 2022

APPLIED SCIENCES

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**69.0**	**73.5**	**78.2**	**81.8**	**102.8**	**106.7**	**109.9**
Change from FY 2022 Budget Request			**4.7**				
Percent change from FY 2022 Budget Request			**6.4%**				

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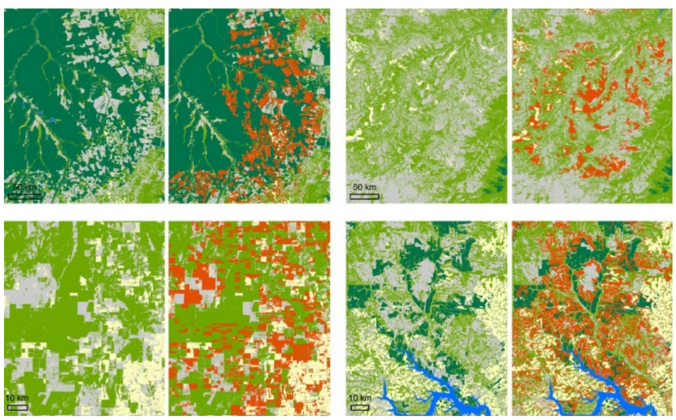


A new study led by NASA Harvest partners at the University of Maryland (UMD) Global Land Analysis and Discovery (GLAD) research group details the exponential expansion of soybean planting in South America since the turn of the century. Agricultural expansion at this scale is determined to have significant implications for Earth's environment and analyzing these types of land use changes provides critical evidence for developing climate change mitigation policies.

The Applied Sciences program leverages NASA Earth Science satellite measurements and new scientific knowledge to enable innovative and practical uses by public and private sector organizations. It supports near-term uses of Earth science knowledge, discovers and demonstrates new applications, facilitates adoption of applications, and builds capabilities.

Applied Sciences projects improve decision-making activities to help the United States better manage its resources, improve quality of life, and strengthen the economy. NASA develops Earth science applications in collaboration with end-users in public, academic, and private organizations.

The program supports activities in thematic Earth science applications areas, in capacity building with uses of Earth observations, and in planning for future NASA missions.

Examples of these applications include:

- The U.S. Department of Agriculture uses NASA soil moisture data to support its monthly global crop production estimates;
- The U.S. Forest Service uses wildfire detection data and progression predictions to improve determination of fire boundaries and to expedite the restoration of key ecosystems;
- The Centers for Disease Control and Prevention's Environmental Public Health Tracking Network includes county-level ultraviolet (UV) exposure information;

APPLIED SCIENCES

- State and local governments use satellite-based water quality data to assess algal bloom magnitude, frequency, duration, and extent to map indicators and threats to human health from harmful algal blooms;
- Disaster-response organizations use data from multiple Earth observing satellites to identify damaged areas following hazards such as hurricanes, floods, and wildfires;
- Tourism industries, coastal resource managers, and others use satellite data to identify the amount and location of Sargassum seaweed in the Atlantic and the Gulf of Mexico to mitigate Sargassum beaching events that cause serious problems for the environment, human health, and economy;
- Local governments use satellite-based land-surface temperature data, emissivity data, and imagery to identify populations most vulnerable to extreme heat and guide service efforts; and
- The Volcanic Ash Advisory Centers use satellite observations of volcanic ash to inform air traffic controllers and the aviation industry of hazards along major airplane routes.

The program sustains the use of these products in the decision-making process of user organizations. The program encourages potential users to envision and anticipate possible applications from upcoming satellite missions and to provide input to mission development teams to increase the societal benefits of NASA missions.

For more information, go to: https://appliedsciences.nasa.gov/

EXPLANATION OF MAJOR CHANGES IN FY 2023

This budget includes a $1 million increase in FY 2023 to expand the development and implementation of wildfire applications in collaboration with the wildfire community and other NASA mission directorates. This budget includes a $3 million increase in FY 2023 to develop user applications for greenhouse gas data.

ACHIEVEMENTS IN FY 2021

On August 9, 2021, the Applied Sciences program released its 2021-2026 Strategic Plan. The plan lays out the program's vision, key principles (inclusion, innovation, integrity, and collaboration), and three goals of Impactful Applications, Knowledgeable and Skilled Communities, and Thriving Collaborations and Private Sector Ventures. The plan positions Applied Sciences to accelerate impacts through project scaling, enable greater user-feedback to NASA, and increase engagement with industries and nonprofits.

To support preparedness and resiliency, the Disasters Support project targeted over 300 partner organizations to strengthen relationships. NASA activated Disaster Assistance Response and Resilience Teams, drawing on five NASA centers and 10 ROSES teams, to support four exercises and 46 activations (10 domestic, 36 international) to guide actions which help exposed and vulnerable communities. In FY 2021, the NASA Disasters Mapping Portal posted 2,501 data products related to events including tropical cyclones, volcanoes, flooding, and wildfires. These activities increased situational awareness for key partners including FEMA, USAID's Bureau of Humanitarian Affairs, The World Food Programme, and The International Federation of Red Cross and Red Crescent Societies.

An Applied Sciences project integrated satellite data into climate action planning tools for assessing air quality and health co-benefits of greenhouse gas mitigation. The C40 Cities' Climate Action Planning

APPLIED SCIENCES

Pathways tool and the Stockholm Environment Institute's Urban LEAP-IBC tool now include satellite-derived PM2.5 (fine, inhalable particulate matter) estimates. In April 2021, Buenos Aires became the first city to include this PM2.5 dataset in their C40 climate action plan.

On December 2, 2020, NASA Harvest, NASA's first agricultural consortium, released a new online dashboard to analyze COVID-19 impacts on agriculture and food security. This NASA Harvest COVID Dashboard helps stakeholders quantify the pandemic's impact on agricultural production and food security worldwide.

On December 10, 2020, the Navajo Nation's new Drought Severity Evaluation Tool (DSET) began operations, following development with Applied Sciences' Western Water Applications Office (WWAO). The DSET tool helps the Navajo monitor and report drought through a combination of precipitation data from NASA satellites, drought indices, and ground-based rain measurements and supports water management. The drought tool is the result of a collaboration between WWAO, the Navajo Nation Department of Water Resources and the Desert Research Institute.

The Capacity Building project continued to build greater knowledge of remote sensing in the United States and around the globe. The SERVIR program element (managed jointly with the U.S. Agency for International Development) worked with its global network to conduct 64 tasks and 68 training sessions that reached over 2,800 individuals from 51 countries. The Applied Remote Sensing Training program element (ARSET) conducted 14 training sessions, with a record reach of 20,658 instances of participation from 155 countries, 55 U.S. states and territories, and more than 8,200 organizations. The DEVELOP program element, a workforce development effort that partners early career professionals with user organizations to apply Earth science data, conducted 50 feasibility projects and engaged 266 young professionals.

WORK IN PROGRESS IN FY 2022

The Applications project will initiate efforts focused on addressing climate impacts and building resilience to shocks and stressors within communities around the country.

The Applications project will initiate environmental justice science efforts to support underserved communities, consistent with the Administration's environmental justice and equity goals.

The Disasters Support project will enable use of NASA Earth science information by the wildfires community. It will do so by pursuing community-based Wildfires Consortiums, which allows for agility in supporting emerging needs.

The Ecological Forecasting program element will initiate efforts to scale conservation efforts in the western United States as a model for conservation globally. Additionally, the program element will have 13 application activities continue this year.

Twenty activities by the third SERVIR Applied Sciences team will begin winding down their work, as they prepare to complete their projects in early FY 2023. Their activities address challenges in food security, weather and climate, land cover, disasters, water resources, and uses of Earth observations for international development. SERVIR will select its fourth Applied Sciences team. SERVIR will also support the development of a sixth hub in Central America deepening the program impact and scaling services within the region and building on the NASA Earth partnership with the Central American Integration System (SICA) in concert with the U.S. Agency for International Development (USAID).

APPLIED SCIENCES

ARSET will conduct approximately plans to conduct 17 training sessions. Learning materials will be available in English and Spanish, with some sessions delivered in both languages.

DEVELOP will conduct 60-65 activities with 240-260 participants working at 11 nodes through a virtual project office.

Applied Sciences will develop plans for a disaster response support office at a NASA Center.

NASA Harvest, NASA's first agriculture consortium, will conclude. Applications will select two consortia for domestic agriculture and international agriculture.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

For the Wildfires initiative, NASA Earth Science Division plans to conduct outreach and site visits, organize and host a series of stakeholder engagement workshops, and create collaborations to: 1) create a shared vision to establish and strengthen the wildfire management system; 2) better understand current science and technological barriers in wildfire risk management; 3) co-develop and build capacity to better utilize wildfire management solutions that leverage the best-available science understanding, technology monitoring and observation, assessment and prediction; and 4) expand applications, including solutions that are proven scalable and sustainable, to the broadest range of wildfire stakeholders, partners and actors. Additionally, NASA Earth Science Division will ensure that various programs within Research, Applications, and Technology work in a coordinated and collaborative manner, targeting resources to deliver substantial improvements wildfire management, as well as working closely with the Aeronautics Research Mission Directorate and Space Technology Mission Directorate to create and leverage efficiencies, partnerships, and value.

NASA will initiate a disaster response support office at a NASA Center to oversee, manage, and coordinate the operational activities associated with sharing Earth science information with organizations with disaster support responsibilities and mandates. This is an organizational reform to improve management and provision of disaster support and does not involve increasing overall funding to Applied Sciences for disaster support. The responsibilities span activities throughout the disaster lifecycle, including preparation through recovery, after-action, and lessons learned. The disaster response support office will have its first full year of supporting emergency managers throughout the disaster lifecycle, including preparation through recovery.

The Applications project will launch two agriculture-focused consortia: one focused on international food security issues and the other focused on domestic agriculture issues.

SERVIR will launch its sixth hub, which will be in Central America.

Program Elements

CAPACITY BUILDING

The Capacity Building project enhances United States and developing countries' capacity (e.g., human, scientific, technological, institutional, and resource capabilities) to make decisions informed by Earth science data and models. Capacity Building develops skills in current and future workforce and creates opportunities in under-served areas to broaden the benefits of Earth observations. This project supports training, information product development, internships, data access tools, short-term application test activities, user engagement, and partnership development. This project has three primary elements:

- SERVIR: A joint venture with USAID that supports developing countries to improve their environmental management and resilience to climate change through uses of Earth observations in development decision-making
- ARSET: A professional-level training program for accessing and using Earth observations data through computer-based webinars and hands-on courses for all types of organizations
- DEVELOP: A national training and development program for individuals to gain experience applying Earth observations through 10-week interdisciplinary activities to address community needs

MISSION AND APPLIED RESEARCH

The Mission and Applied Research project enables involvement by applications-oriented users in the planning and development of Earth Science satellite missions. It enables end-user engagement to identify applications early in and throughout the mission life cycle, and integrates end-user needs in design and development, enabling user feedback and broadening advocacy. Mission and Applied Research organizes community workshops to identify priority needs as well as studies to inform design trade-offs and identify ways to increase the applications value of missions. This project advises flight projects on activities to develop the applications dimension of a mission in development to help broaden benefits and maximize the return from the investment in the mission.

DISASTER SUPPORT

The Disaster Support project enables development of innovative applications using NASA satellite mission data as well as other activities to ensure timely, valuable support to responders when disasters occur. The Disaster Support project sponsors the use and integration of Earth observations in the decisions and actions of disaster-related organizations, including use of feasibility studies, in-depth activities, workshops, and needs assessments. The project also sponsors activities to improve a preparatory-based approach to enhance value and usability of NASA Earth Science products in support of disaster response and recovery across a wide range of disaster types including floods, earthquakes, volcanoes, and landslides. This project pursues partnerships with disaster groups that can carry forward NASA-developed information and tools to support the responders they serve. The project will begin to focus greater attention on supporting disaster risk assessment and disaster resilience.

APPLICATIONS

The Applications project sponsors the integration of Earth observations in the decisions and actions of community organizations. There are formal applications program elements in Ecological Forecasting, Food Security and Agriculture, Health and Air Quality, and Water Resources. The applications program elements support feasibility studies, in-depth activities, applied science teams, consortia, workshops, and needs assessments. Each applications program element participates in major conferences and events that their partners attend to meet and engage managers and users.

- Agriculture: The agriculture applications program element promotes the use of Earth observations for the functioning and resilience of food systems. The area supports a multi-organizational consortium to enhance domestic and international food security and improved agricultural practices, especially for economic progress and humanitarian pursuits.

- Climate: The climate application program element supports uses of Earth science information to inform climate-relevant policy analyses and understanding resilience and climate risks. This area will conduct work through solicitation efforts for applied research and applications development. Additionally, this area will seek to build resilience in the private sector (commercial and non-profit) to climate shocks and stressors.
- Ecological Forecasting: The ecological forecasting applications program element promotes the use of Earth observations and models to analyze and forecast changes that affect ecosystems and to develop effective resource management strategies. Primary user communities are natural resource managers (both land and marine) and those involved in conservation and sustainable ecosystem management.
- Energy: The major component of the energy application program element is the Prediction of Worldwide Energy Resources (POWER) tool. POWER is a web-based platform that provides solar and meteorological data sets to support the renewable energy, building design, and energy efficiency industries.
- Environmental Justice: The Environmental Justice Advisory Council has defined environmental justice communities as "geographic locations with significant representation of persons of color, low-income persons, indigenous persons or members of Tribal nations, where such person's experience, or are at risk of experiencing, higher or more adverse human health or environmental outcomes." The environmental justice program element builds connections with communities to co-develop uses of Earth and social science to advance equity and environmental justice. This program element will support environmental justice communities by expanding awareness, accessibility, and use of Earth science data and enabling contributions to Earth science pursuits.
- Food Security and Agriculture: The food security and agriculture applications program element promotes the use of Earth observations along the value chain for the functioning and resilience of food systems. The program element supports a multi-organizational consortium to enhance domestic and international food security and improved agricultural practices, especially for economic progress and humanitarian pursuits.
- Health and Air Quality: The health and air quality application program element promotes the use of Earth observations data and models in the implementation of air quality standards, policy, and regulations for economic and human welfare (particularly involving environmental health and infectious diseases). This program element addresses issues of toxic and pathogenic exposure and health-related hazards and their effects for risk characterization and mitigation.
- Water Resources: The water resources applications program element supports the use of Earth observations in water resources management related to water demand, supply, and quality. The program element includes five functional themes: drought, streamflow and flood forecasting, evapotranspiration and irrigation, water quality, and climate effects on water resources.
- Wildfires: The wildfires applications program element supports applications across pre-, active, and post-fire phases. Initial focus will be on tools, collaborations, and modeling on fuel-load and fire-risk. This program element will pursue joining community consortia for agility in scope and duration of projects.

In addition to these activities, the Applications project supports the following initiatives:

APPLIED SCIENCES

- NASA Harvest Consortium: The program sponsors a multi-organizational consortium to advance the use of Earth observations for enhanced food security and improved agricultural practices, especially benefitting private sector stakeholders domestically and humanitarian efforts internationally.
- Group on Earth Observations (GEO) Work Programme: Applied Sciences supports specific elements in the GEO Work Programme to further U.S. and NASA interests internationally, leveraging resources of other countries and organizations. This initiative specifically fosters a broader involvement of domestic organizations in a U.S. national approach to GEO and the Work Programme, increasing opportunities for these organizations.
- VALUABLES Consortium: The Valuation of Applications Benefits Linked to Earth Science (VALUABLES). The program supports a multi-organizational consortium to support the development of analytic techniques to quantify the benefits, in social and economic terms, from uses of Earth observations to improve decisions. VALUABLES also helps build familiarity in the Earth science community with concepts and methods and helps communicate the benefits of Earth observations.
- Western Water Applications Office: The Western Water Applications Office (WWAO) is a targeted initiative to contribute Earth observations to help solve important and pressing water-resource problems faced by the western United States. WWAO involves several NASA centers to engage public and private sector stakeholders in the western water management community for innovative ways to apply Earth observations in managing water supply and accommodating a growing demand.

Program Schedule

Date	Significant Event
Q1 FY 2022	ROSES-2021 selection within six to nine months of receipt of proposals
Q2 FY 2022	ROSES-2022 solicitation release
Q1 FY 2023	ROSES-2022 selection within six to nine months of receipt of proposals
Q2 FY 2023	ROSES-2023 solicitation release
Q1 FY 2024	ROSES-2023 selection within six to nine months of receipt of proposals
Q2 FY 2024	ROSES-2024 solicitation release
Q1 FY 2025	ROSES-2024 selection within six to nine months of receipt of proposals
Q2 FY 2025	ROSES-2025 solicitation release
Q1 FY 2026	ROSES-2025 selection within six to nine months of receipt of proposals
Q2 FY 2026	ROSES-2026 solicitation release
Q1 FY 2027	ROSES-2027 selection within six to nine months of receipt of proposals
Q2 FY 2027	ROSES-2027 solicitation release

APPLIED SCIENCES

Program Management and Commitments

Program Element	Provider
Applications	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC Cost Share Partner(s): U.S. Forest Service, National Park Service (NPS), U.S. Department of Agriculture (USDA), National Oceanic and Atmospheric Administration (NOAA), U.S. Geological Survey (USGS), U.S. Fish and Wildlife Service, Environmental Protection Agency (EPA), Bureau of Land Management, Centers for Disease Control and Prevention
Capacity Building	Provider: Various Lead Center: LaRC, MSFC, GSFC Performing Center(s): ARC, GSFC, JPL, MSFC, LaRC Cost Share Partner(s): USGS, Groundwork USA, USDA, University of Georgia, NOAA, Arizona State University, Boston University, USAID, EPS, NOAA, NWS
Disaster Support	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC Cost Share Partner(s): Department of Homeland Security (DHS), NOAA, USDA, USGS, USAID, USACE, National Guard
Mission and Applied Research	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC Cost Share Partner(s): USDA, CNES, ISRO, Joint Research Centre (JRC), European Space Agency

Acquisition Strategy

NASA bases the Earth Science Applied Science acquisitions on full and open competition. Grants are peer reviewed and selected based on NASA research announcements and other related announcements.

APPLIED SCIENCES

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Relevance	Applied Sciences Advisory Committee	Jul 2020	Review Applied Sciences Program activities	Provided recommendations on the use of consortia as a programmatic model and opportunities for beneficial engagement with other parts of ESD.	Dec 2021
Relevance	Applied Sciences Advisory Committee	Dec 2021	Review strategy and implementation	TBD	Jul 2022

PLANETARY SCIENCE

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Planetary Science Research	304.1	309.0	**298.6**	299.4	309.3	324.9	342.3
Planetary Defense	158.1	202.1	**87.7**	116.5	181.5	242.5	247.7
Lunar Discovery and Exploration	443.5	497.3	**486.3**	458.3	458.3	458.3	468.3
Discovery	447.7	336.7	**230.0**	369.6	540.5	594.7	686.4
New Frontiers	150.9	288.7	**478.4**	415.0	453.8	409.6	401.1
Mars Exploration	339.5	270.7	**233.9**	223.8	211.7	226.8	242.1
Mars Sample Return	241.6	653.2	**822.3**	800.0	700.0	600.0	612.1
Outer Planets and Ocean Worlds	461.5	493.7	**356.8**	313.8	130.3	120.5	127.9
Radioisotope Power	146.3	148.6	**166.3**	189.7	212.1	199.2	171.0
Total Budget	**2,693.2**	**3,200.0**	**3,160.2**	**3,186.1**	**3,197.4**	**3,176.4**	**3,299.0**

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Planetary Science

PLANETARY SCIENCE RESEARCH

FY 2023 Budget

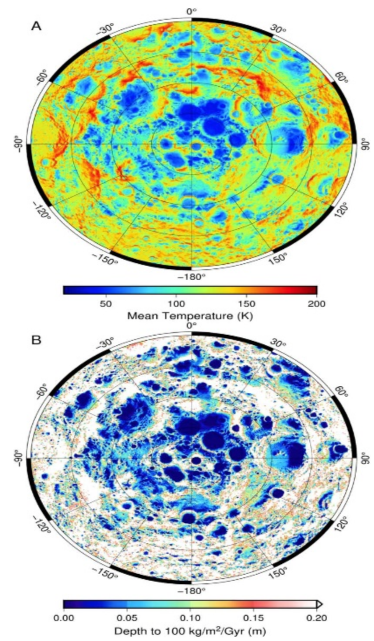
Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Planetary Science Research and Analysis	223.2	221.3	**213.1**	216.6	226.3	230.0	219.4
Other Missions and Data Analysis	80.9	87.8	**85.5**	82.8	83.0	94.8	122.9
Total Budget	**304.1**	**309.0**	**298.6**	**299.4**	**309.3**	**324.9**	**342.3**
Change from FY 2022 Budget Request			**-10.4**				
Percent change from FY 2022 Budget Request			**-3.4%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The Planetary Science Research program provides the scientific foundation for data returned from NASA missions exploring the solar system. It is also NASA’s primary interface with university faculty and graduate students in this field and with the research community in general. The program develops analytical and theoretical tools, as well as laboratory data, to support analyses of flight mission data. These capabilities allow Planetary Science to answer specific questions about, and increase the understanding of, the origin and evolution of the solar system. The research program achieves this by supporting research grants solicited annually and subjected to a competitive peer review before selection and award. The Planetary Science Research program focuses on five key research goals:

- Advance the understanding of how the chemical and physical processes in our solar system operate, interact, and evolve;
- Explore and observe the objects in the solar system to understand how they formed and evolve;
- Explore and find locations where life could have existed or could exist today;
- Improve our understanding of the origin and evolution of life on Earth to guide our search for life elsewhere; and
- Identify and characterize objects in the solar system that pose threats to Earth or offer resources for human exploration



Average surface temperature, in Kelvin, (A) and estimated depth to which 100 kg per square meter of ice is stable for a billion years (B) in the lunar south polar region (to latitude 80°S). The maps shown above indicate that surface or subsurface ice is likely to be stable and extensive across the area. Reference: Schorghofer and Williams, 2020.

EXPLANATION OF MAJOR CHANGES IN FY 2023

An additional $1 million is provided to the Robotics Alliance Project to increase participation of students from underserved and

PLANETARY SCIENCE RESEARCH

underrepresented communities in challenging applications of engineering and science, including national robotic competitions in which high school students team with engineering and technical professionals from Government, industry, and universities to gain hands-on experience and mentoring.

ACHIEVEMENTS IN FY 2021

NASA's Voyager 2 mission revealed that cryovolcanism, which is volcanic activity that occurs in environments with extremely low temperatures, may have formed some of the geological features on the surfaces of the mid-sized Uranian moons, hinting at ocean world activity, now or in the past. Ammonia is an efficient anti-freeze agent that is associated with cryovolcanic deposits and processes on confirmed ocean worlds like Enceladus and Ceres. Using NASA's Infrared Telescope Facility, a team detected a band of light emission around 2.2 microns on Ariel and the other Uranian moons that is consistent with the presence of ammonia-bearing molecules, supporting the photogeologic evidence for cryovolcanism on the Uranian moons.

For two years, the Mars lander, Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight), has recorded seismic data on Mars that are vital to understanding the structure and thermochemical state of the planet and its geologic history. Results from the InSight mission have already demonstrated that Mars is seismically active. Marsquakes are plentiful, albeit small in magnitude. The first measurement analyses of the interior structure of Mars provide direct observations revealing a 24- to 72-km-thick layered crust and 500 km deep lithosphere; a crust likely to be highly enriched in radioactive elements; and a liquid and large ~1,830 km iron-nickel core enriched in light elements. These results point to a planet's interior that evolved differently from Earth.

Earth's status as the only known life-sustaining planet is a result of the timing and delivery mechanism of carbon, nitrogen, sulfur, hydrogen, and the identity of the body that delivered this material to early Earth. Based on their isotopic signatures, terrestrial volatiles (small molecules) are thought to have derived from carbonaceous meteorites, while the isotopic compositions of nonvolatile major and trace elements suggest that a different type of meteorite material composes the primary building blocks of Earth. Using experiments at high pressure and temperature and modeling simulations, researchers have demonstrated that an impact of a Mars-sized planet and composition, around the time of the Moon-forming event (five to ten million years after the formation of the solar system), could be the source of major volatiles on the Earth.

The study of an extreme outburst, or flare, from the Sun's nearest neighbor—the star Proxima Centauri—, could help guide the search for life beyond our solar system. A cross-disciplinary team of astronomers, heliophysicists, and planetary scientists discovered the flare by using the Hubble Space Telescope (HST); Transiting Exoplanet Survey Satellite (TESS); and ground-based telescopes that included the Australian Square Kilometre Array Pathfinder (ASKAP), Atacama Large Millimeter/submillimeter Array (ALMA), and the du Pont Telescope. Proxima Centauri is a "red dwarf" with about one-eighth the mass of the Sun, which sits just four light-years, or almost 25 trillion miles, from the center of the solar system and hosts at least two planets, one of which may look something like Earth. As the closest exoplanet to Earth, and located in the star's habitable zone, Proxima B is the most likely candidate for follow-up observations and astrobiological surveys. But according to the latest study, the flares it emits would have likely rendered the planet sterile a long time ago. The team's findings constitute one of the most in-depth anatomies of a flare from any star in our galaxy. In the future, these

PLANETARY SCIENCE RESEARCH

signals could help researchers gather more information about how stars generate flares, which could have immense implications for exoplanet and habitability studies and for astrobiological investigations into the search for life beyond Earth.

After its discovery in 2004, asteroid 99942, Apophis (estimated to be about 1,100 feet [340 meters] across), was one of the most hazardous asteroids that could impact Earth. Apophis quickly gained notoriety as an asteroid that could pose a serious threat to Earth when astronomers predicted that it would come uncomfortably close in 2029. Thanks to additional observations of the near-Earth object (NEO), the team later ruled out the risk of an impact in 2029, as well as the potential impact risk posed by another close approach in 2036—but determined that a small chance of impact in 2068 still remained. When Apophis made a distant flyby of Earth around March 5, 2021, astronomers took the opportunity to use the Goldstone Solar System Radar to precisely track Apophis' motion and to refine the estimate of its orbit around the Sun with extreme precision, enabling scientists to confidently rule out any impact risk in 2068 and long after.

Early observations have long suggested that the lunar poles harbor water ice due to the abundance of large regions with low temperatures, including some large areas of permanent shadow. Data from the Lunar Reconnaissance Orbiter show that searching for regions with lower sublimation rates better identifies the many unmapped cold traps that exist. These newly-discovered traps imply an increase in the amount of ice thought to exist on the Moon by at least 25%. The data show that the regions where water molecules and the regolith efficiently pump together are larger than the subsurface cold traps by roughly a factor of five. Theoretical models and orbital observations predict the formation of water ice in shadows at scales of 1 km to 1 cm. The smallest of these scales, 1 cm, is the minimum scale where water ice forms. The new maps of cold traps, subsurface ice stability, and thermally pumped ice provide more-accurate information on the geographic distribution of potential water-ice deposits in the south polar region. The maps show that the extent of ice-bearing deposits is much greater than previously thought and thus increase interest in the potential regions for future exploration of the lunar south polar.

WORK IN PROGRESS IN FY 2022

FY 2022 plans in the core elements of the Research & Analysis (R&A) portfolio include:

- The Solar System Workings (SSW) element expects to fund approximately 40 new research activities including atmospheric, climatological, dynamical, geologic, geophysical, and geochemical processes of the various bodies in the solar system using techniques ranging from laboratory experiments to analysis of observational data to theoretical modeling.
- The Emerging Worlds (EW) element, focused on the formation of the solar system, expects to fund approximately 30 new research awards that may address individual topics ranging from the earliest stages of solar system formation to the final events that led to the solar system as we know it today.
- The Habitable Worlds (HW) element expects to fund approximately 10 new research awards focusing on topics relating to the presence of water and/or exotic solvents, sources of energy for life, the presence of organics and their reactivity, and water body physics and chemistry as they pertain to habitability and habitability over time, as well as space weather signatures that may be indicative of impacts to planetary habitability.

PLANETARY SCIENCE RESEARCH

- The Exobiology element will support research into the potential for life beyond Earth and expects to fund approximately 25 new investigations in five major sub-themes: Prebiotic Chemistry, Early Evolution of Life and the Biosphere, Evolution of Advanced Life, Large Scale Environmental Change and Macro-Evolution, and Biosignatures and Life Elsewhere.
- The Near-Earth Object Observations element supports research investigations that address this theme through the Yearly Opportunities in Research for Planetary Defense (YORPD) solicitation. NASA expects approximately 10 new selections, including both large-scale observing programs designed for the detection and tracking of near-Earth objects, and smaller research programs aimed at characterizing the physical properties of such bodies.

In FY 2022, NASA will initiate a new research element to increase access to scientific laboratories with advanced measurement capabilities. This element started in response to a study carried out by the National Academies (Strategic Investments in Instrumentation and Facilities for Extraterrestrial Sample Curation and Analysis, 2019), and includes provisions for broad community access to such facilities and an emphasis on collaboration with and involvement of diverse groups of researchers. Increased access to the facilities, laboratories, and equipment will begin in late FY 2022. NASA also plans to make FY 2022 selections within the Data Analysis and Participating Scientist Program (PSPs) elements. NASA will continue technology development initiatives, such as the Planetary Instrument Concepts for the Advancement of Solar System Observations (PICASSO) and the maturation of Instruments for Solar System Exploration (MatISSE) to support the development of innovative new instruments that will enable or improve future scientific observations on future missions.

In the Astromaterial Curation project, final preparation for return of OSIRIS-REx asteroid samples will culminate in FY 2022 in preparation for the spacecraft return to Earth on September 24, 2023. With International Standards Organization 5 (ISO5) sample cleanroom construction and certification complete and lab outfitting initiated, operational activities will include sample recovery planning and rehearsals at the Utah Test and Training Range. The project will conduct rehearsals for sample receiving and conduct the Touch and Go Sample Acquisition Mechanism head disassembly. NASA will conduct an operational readiness review for the sample curation lab once final outfitting of the cleanrooms is complete. NASA will receive the Hayabusa2 sample allocation from Japan Aerospace Exploration Agency (JAXA). Researchers will carefully put the individual grains into secured separate containers, photograph and catalogue them, and publish results online. Initial characterization will divide samples into organic rich or mineral dominant sub-groups for international sample investigation opportunities.

Planetary R&A also continues support for the Planetary Science & Astrobiology Decadal Survey, with the final report expected in mid-FY 2022. Following publication of the report, the research program will evaluate whether changes to the fundamental planetary science themes are needed, and if so, how to best match the individual R&A elements to such changes.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

In pursuit of fundamental science that guides planetary exploration, the Planetary Science Research program will continue to select highly rated R&A proposals that support planetary missions and goals. As described above, the individual programs within the R&A portfolio directly address the major scientific themes identified for Planetary Science and these programs will continue in the coming year. Planetary

PLANETARY SCIENCE RESEARCH

science will also continue archiving and distributing relevant mission data to the science community and the public in a timely manner.

In FY 2023, the R&A program will also continue evaluation of the individual program elements to ensure alignment with the priorities identified by the next Decadal Survey.

In the Robotics Alliance project, NASA organizers will increase participation of students from underserved and underrepresented communities in challenging applications of engineering and science, including national robotic competitions.

Program Elements

PLANETARY SCIENCE RESEARCH AND ANALYSIS (R&A)

Planetary Science R&A enhances the scientific return from on-going and completed spaceflight missions and provides the foundation for the formulation of new scientific questions and strategies for answering those questions. R&A develops new theories and instrumentation concepts that enable the next generation of spaceflight missions. R&A funds research tasks in areas such as astrobiology and cosmochemistry; the origins and evolution of planetary systems; the observation and characterization of extra-solar planets (i.e., exoplanets); and the atmospheres, geology, and chemistry of the solar system's bodies other than the Earth or the Sun.

Program Schedule

The Planetary Science Research Program solicits proposals as part of the Science Mission Directorate's annual Research Opportunities in Space and Earth Sciences (ROSES) research calls. The program issues solicitations every year. A Senior Review process assesses all missions in the extended operations phase every three years and all data archives every five years.

Date	Significant Event
Feb 2022	ROSES-2022 NRA solicitation released
Mar-Apr 2022	Senior Review Operating Missions
Q1 FY 2023	ROSES-2022 selection within six to nine months of receipt of proposals
Feb 2023	ROSES-2023 NRA solicitation release
Q1 FY 2024	ROSES-2023 NRA selection within six to nine months of receipt of proposals
Feb 2024	ROSES-2024 NRA solicitation release
Q1 FY 2025	ROSES 2024 NRA selection within six to nine months of receipt of proposals
Feb 2025	ROSES-2025 NRA solicitation release
Mar-Apr 2025	Senior Review Operating Missions

PLANETARY SCIENCE RESEARCH

Date	Significant Event
Q1 FY 2026	ROSES-2025 NRA selection within six to nine months of receipt of proposals
Q4 FY 2026	Senior Review Data Archives Discipline Nodes
Q3 FY 2027	Senior Review Data Archives Support Nodes

Program Management & Commitments

Program Element	Provider
R&A	Provider: NASA Lead Center: Headquarters (HQ) Performing Center(s): Ames Research Center (ARC), Glenn Research Center (GRC), Goddard Space Flight Center (GSFC), Jet Propulsion Laboratory (JPL), Johnson Space Center (JSC), Langley Research Center (LaRC), Marshall Space Flight Center (MSFC) Cost Share Partner(s): N/A

Acquisition Strategy

The R&A budget will fund competitively selected activities from the ROSES omnibus research announcement.

INDEPENDENT REVIEWS

The Advanced Multi-Mission Operations System (AMMOS) had two independent reviews in 2021 of their multi-mission strategy. These reviews verified long-term value to planetary missions and spin-off value to other space domain users.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	AMMOS Independent Review Board (AIRB)	2021	Prioritize multi-mission development tasks for AMMOS	Continue current multi-mission development approach	2024
Relevance	AMMOS Capabilities Review Committee Zero Based Audit (CRC ZBA)	2021	Assess future multi-mission needs in alignment with direction for AMMOS	AMMOS is performing well, has world-class products and is on track to meet the needs of the near future.	2024

PLANETARY SCIENCE RESEARCH

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	Planetary Science Advisory Committee (PAC)	2022	Annual review to assess progress against strategic objectives of Planetary Science.	TBD	2023
Relevance	Planetary Science Decadal Survey	2022	Provide recommendations on strategic direction for the Planetary Science Division	TBD	2032

OTHER MISSIONS AND DATA ANALYSIS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Advanced Multi-Mission Operation System	39.9	40.5	**40.5**	38.0	38.0	38.0	37.7
Planetary Science Directed R&T	0.0	0.0	**0.0**	0.0	0.0	10.3	39.0
Planetary Data System	24.1	27.3	**27.8**	28.4	28.6	28.5	28.2
Astromaterial Curation	12.9	16.0	**12.1**	12.4	12.4	14.0	14.0
Robotics Alliance	4.0	4.0	**5.0**	4.0	4.0	4.0	4.0
Total Budget	**80.9**	**87.8**	**85.5**	**82.8**	**83.0**	**94.8**	**122.9**
Change from FY 2022 Budget Request			**-2.3**				
Percent change from FY 2022 Budget Request			**-2.6%**				

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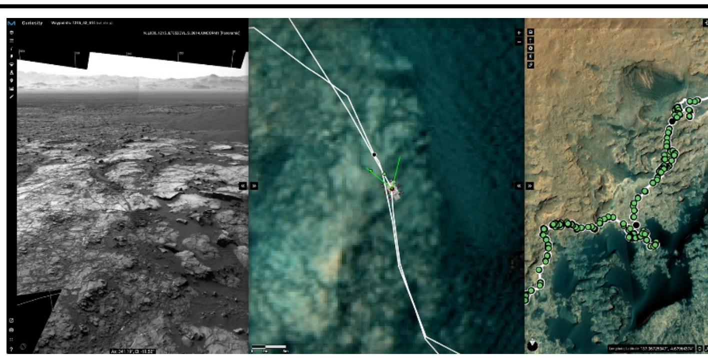


The image above depicts the Mars Science Laboratory (MSL) mission planning data in the AMMOS. The AMMOS Multi-Mission capabilities provide Martian rover science operations teams with advanced capabilities to visualize and interact with the Martian environment to maximize science objectives. Pictured above, team members may view contextual information, local position and orientation, and view imagery acquired in that location to support rover planning needs.

Other Missions and Data Analysis includes activities and infrastructure that support NASA Planetary Science Research and missions, such as the Advanced Multi-Mission Operation System, Planetary Data System, and Astromaterial Curation.

Mission Planning and Other Projects

ADVANCED MULTI-MISSION OPERATION SYSTEM (AMMOS)

AMMOS is a system of reusable software tools and services comprising a mission ground operations and ground data system used across multiple NASA missions. AMMOS provides multi-mission operations, navigation, design, and training tools and services for Planetary Science flight missions, as well as other Science Mission Directorate missions, and invests in improved communications and navigation technologies. The AMMOS project will continue to provide and develop multi-mission software tools for spacecraft navigation, command, control, assessment, mission planning, and data archiving. Utilizing the AMMOS common tools and services lowers individual mission cost and risk by providing a mature base for mission operations systems at significantly reduced development time. AMMOS also provides support to our international space agency partners on an as-needed basis. This

OTHER MISSIONS AND DATA ANALYSIS

support typically pertains to navigation assistance and scheduling of NASA's Deep Space Network (DSN) assets.

AMMOS currently provides multi-mission operations tools and services to 87 missions, which is an increase of over 20 percent in the past year, and includes support to Planetary Science, Heliophysics, Earth Science, and Astrophysics missions within NASA and critical operations services to 14 international missions. AMMOS continues to provide critical NASA support to international missions from the Canadian Space Agency (CNES), the German Aerospace Center (DLR), the European Space Agency (ESA), the Indian Space Research Organization (ISRO), the Japan Aerospace Exploration Agency (JAXA), the Korea Aerospace Research Institute (KARI), and United Arab Emirates Space Agency.

Operating missions enabled by AMMOS include the Mars Rover 2020 Perseverance rover, Parker Solar Probe, Chandrayaan-2, InSight, Origins Spectral Interpretation Resource Identification and Security-Regolith Explorer (OSIRIS-REx), Mars Atmosphere & Volatile EvolutioN (MAVEN), Chandra X-ray Observatory, Lucy, among many others. Missions currently in development enabled by AMMOS include Europa Clipper, Volatiles Investigating Polar Exploration Rover, Janus, Psyche, Lunar Trailblazer, NASA CubeSats Near-Earth Asteroid (NEA) Scout and Lunar Flashlight, and nanosatellites Lunar IceCube and ArgoMoon, among others.

Recent Achievements

The AMMOS Navigation Ancillary Information Facility (NAIF) toolkit named "SPICE " is used worldwide to help scientists and engineers compute a wide assortment of space mission geometry (e.g., instruments and spacecraft positions, ranges, planetary target body size and shape, orientations, and velocities). Over the last four years, individual IP addressed downloaded the SPICE toolkit over 30,000 times. In addition to NASA, United States institutions, and ESA, other international agencies from Canada, France, Germany, India, Italy, Japan, Russia, South Korea, and the United Arab Emirates utilize NAIF SPICE.

AMMOS continues to prioritize advancement in platform modernization including automated testing and deployment and continues its push towards software open source to increase its customer base and further adoption of cloud technology for operations. In FY 2021 AMMOS developed command encryption in collaboration with NASA's Independent Verification and Validation (IV&V) facility, the first multi-mission NASA-developed capability. These advancements should enable significant cost savings to future missions by lowering the level of mission specific system adaptations.

AMMOS integrated the Delay Tolerant Network (DTN) Interplanetary Overlay Network (ION) software with its SmallSat mission control offering to enable support for Morehead State University's DTN operation of Lunar IceCube, a NASA nanosatellite mission to prospect, locate, and estimate the amount and composition of water ice deposits on the Moon.

PLANETARY SCIENCE DIRECTED RESEARCH AND TECHNOLOGY

The Planetary Science Directed Research and Technology project funds the civil service staff who work on emerging Planetary Science flight projects, instruments, and research.

OTHER MISSIONS AND DATA ANALYSIS

PLANETARY DATA SYSTEM (PDS)

The PDS is an online data archive that furthers NASA's Planetary Science goals by efficiently collecting, archiving, and making accessible digital data produced by, or relevant to, NASA's planetary missions, research programs, and data analysis. This curated archive includes raw and fully calibrated orbital and surface observations from hundreds of NASA missions and instruments exploring the solar system planets, asteroids, and small bodies. The PDS archives now span more than 50 years of NASA-funded research and its holdings are now expanding to include ground-based observations of Near-Earth objects (NEOs). The PDS archives are publicly available through the PDS website. NASA is incorporating new PDS enhancements including a plan for unification of the PDS website intended to make data easier to find and access, adopting a cloud computing strategy that will increase access to super-computing time, and continuing to create training modules for finding and using PDS data.

Recent Achievements

The PDS received and released data from 20 active planetary missions since October 2020 and continued to release enhanced legacy data. The PDS website has served over 1.5 million unique visitors, domestic and international, who downloaded over 150,000 files. The PDS currently contains approximately two petabytes of data from over 70 missions and recently began work with several United States companies through the Commercial Lunar Payload Service (CLPS) to ensure the successful delivery of CLPS payload data. The PDS took part in an independent review of the Planetary Data Ecosystem followed by a programmatic review of the Discipline Nodes, which resulted in renewals of cooperative agreements, contracts, and Interagency Agreements governing the Discipline Nodes. Added objectives include, but are not limited to, accelerating the migration of PDS3 to PDS4 metadata standards to increase searchability and discoverability; creating a unified web presence to enhance user experience; plans for cloud computing and migration of specific datasets to the cloud storage; and adding a Radio Science data node.

The PDS also continued to support data providers from over 300 NASA research program investigations, including archive support for data from ground-based observations, laboratory analyses, field observations, the production of other higher order data sets, and the restoration of old datasets. Migration of data from PDS3 to PDS4 standards continued, laying the cornerstone for the future user's enhanced and modern interaction with the PDS. As a result of these activities, the PDS archive grew in volume by approximately 150 terabytes to total approximately 2.0 petabytes.

ASTROMATERIAL CURATION

The Astromaterials Acquisition and Curation Office at Johnson Space Center (JSC) curates extraterrestrial material under NASA control. Curation is an integral part of sample return missions. Activities conducted by the Curation office include: (1) research into advanced curation techniques to support future missions; (2) sample return mission planning; (3) archiving of witness, engineering, and reference materials related to sample return missions; (4) recovery and transport of returned materials; (5) initial characterization of new samples; (6) preparation and allocation of samples for research; and (7) providing clean and secure storage for the benefit of current and future generations.

Materials currently curated include: Antarctic meteorites; cosmic dust; samples collected from the Moon; samples of the solar wind; samples from comet 81P/Wild; dust collected in interstellar space; particles from asteroid Itokawa; cosmic dust collected in Earth's stratosphere; microparticle-impacted flight hardware; witness materials (small foils and plates placed in spacecraft assembly cleanrooms to collect molecules and particles); and coupons (representative pieces of materials used in construction of

OTHER MISSIONS AND DATA ANALYSIS

spacecraft) for several past, present, and future sample-return missions, including Apollo, LDEF, Genesis, Stardust, OSIRIS-REx, and Mars 2020. Planning and research efforts are currently underway to develop the technologies and procedures for proper curation of samples from current and future missions to the Moon (i.e., Artemis), asteroids (OSIRIS-REx and Hayabusa2), Mars (Mars Sample Return [MSR] campaign), and Mars' moon Phobos (Martian Moons eXploration [MMX]). NASA plans to receive Hayabusa2 and MMX samples under international agreements with JAXA. New laboratory space construction is complete and in preparation to receive the OSIRIS-REx and Hayabusa2 samples, as well as to do advanced cleaning and curation research; however, the facility must still be certified and outfitted.

Recent Achievements

The project maintains eight existing collections of astromaterials in pristine condition for scientific research within 22 cleanrooms at JSC and White Sands Test Facility. In 2020, the team allocated more than 650 samples to scientists across the world, despite six months of lab closure due to the COVID-19 pandemic.

Construction for new cleanrooms for OSIRIS-REx and Hayabusa2 is complete, as is the archiving of construction materials for contamination knowledge. JAXA transferred NASA's share of the Hayabusa2 samples, ~0.5 grams of asteroid Ryugu regolith materials, in late November 2021. NASA developed detailed procedures for disassembly of the OSIRIS-REx sample canister and touch and go sample acquisition mechanism (TAGSAM), with many rehearsals and activities completed in FY 2021 and planned in FY 2022 and FY 2023 to be ready for the arrival of samples in September 2023. The mission science team is helping develop sample containers, nomenclature, sample handling documentation, and sample preparation techniques.

The Curation project is working to optimize future science by ensuring proper sample handling for the MSR and Artemis missions. As part of MSR preparation, JSC is working with JPL to complete a benchmarking report on implementation strategies for receiving and processing future samples. JSC Curation is currently receiving and curating items that record the contamination environment for the Mars Rover 2020 spacecraft, including witness plates, witness items, and material coupons that record inorganic, organic, and biological contamination. These contamination knowledge samples will be part of the Mars sample collection and used to baseline contamination during future analysis of returned Martian samples.

Following a year of mandatory telework, the Curation project has been working to bring existing lab equipment back online safely. With completion of facility construction, the project will conduct laboratory readiness reviews in FY 2022 to ensure labs are safe and technically ready to receive samples. Outfitting the newly renovated labs are a major focus in FY 2022, including a benchtop X-ray fluorescence system to complement the recently installed scanning Raman spectrometer for non-destructive characterization of astromaterials. The team certified the new Hayabusa2 cleanroom at the end of CY 2021 and is conducting dress rehearsals to ensure readiness to secure Ryugu samples transferred from JAXA to JSC.

Finally, the Curation project is developing methods for archiving the data produced by missions and other researchers during the chemical and physical analysis of curated samples and linking these data to curation catalogs and databases.

OTHER MISSIONS AND DATA ANALYSIS

ROBOTICS ALLIANCE PROJECT

The Robotics Alliance Project (RAP) increases interest in engineering, technology, science, and mathematics disciplines among youth in the United States to create an inspired, experienced, and technical workforce for the aerospace community. Annual activities and events expose students to challenging applications of engineering and science, including national robotic competitions in which high school students team with engineering and technical professionals from Government, industry, and universities to gain hands-on experience and mentoring.

Recent Achievements

In FY 2021, RAP sponsored approximately 1,677 United States-based teams (approximately 42,000 students) in the For the Inspiration and Recognition of Science and Technology (FIRST) Robotics Competition, as well as 50 VEX Robotics Competition teams (approximately 500 students). Due to the COVID-19 pandemic, the FIRST and VEX programs significantly restructured, foregoing the traditional in-person competition structure in lieu of virtual/remote competitions. As a result, a larger number of FIRST teams received more support, albeit at a lower level, from the RAP resources. NASA anticipates that in-person team support will return next year to the previous levels as the competition structure returns to the traditional format.

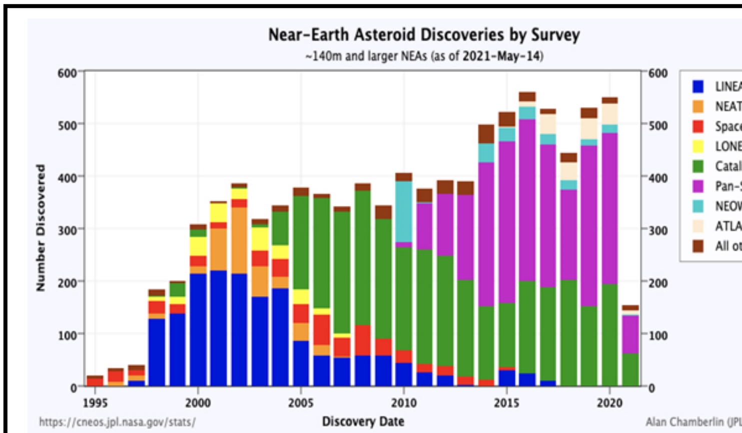
PLANETARY DEFENSE

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
NEO Surveyor	31.3	143.2	**39.9**	75.0	140.0	200.0	200.0
Other Missions and Data Analysis	126.8	58.9	**47.8**	41.5	41.5	42.5	47.7
Total Budget	**158.1**	**202.1**	**87.7**	**116.5**	**181.5**	**242.5**	**247.7**
Change from FY 2022 Budget Request			**-114.4**				
Percent change from FY 2022 Budget Request			**-56.6%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



This graph depicts yearly progress in discoveries of near-Earth asteroids larger than 140 meters in size. Credit: NASA/JPL-Caltech.

NASA's Planetary Defense program focuses on projects that detect and provide follow-up observations for precision orbit determination and physical characterization of asteroids and comets with the potential to impact Earth.

Planetary defense involves:

- Finding and tracking near-Earth objects (NEOs) that pose a hazard of impacting Earth;
- Ensuring the early detection of potentially hazardous objects (PHOs), asteroids, and comets whose orbit are predicted to bring them within 0.05 Astronomical Units, about 5 million miles, of Earth's orbit; and of a size large enough to reach Earth's surface, with a focus on objects 140 meters or greater in size that can cause significant damage at regional scales;
- Characterizing those objects to determine their orbit trajectory, size, shape, mass, composition, rotational dynamics, and other parameters so that experts can determine the severity of the potential impact event, warn of its timing and potential effects, and determine the means to mitigate the impact; and
- Planning and implementation of measures to deflect or disrupt an object that's on an impact course with Earth, or to mitigate the effects of an impact that cannot be prevented.

The Planetary Defense Coordination Office (PDCO) manages the Planetary Defense program. PDCO administers the Near-Earth Object Observations (NEOO) project, which funds, and coordinates efforts to

PLANETARY DEFENSE

find, track, and characterize any asteroid or comet that could become an impact hazard to Earth. Scientists conduct these NEO observation efforts at observatories supported by NASA on the ground and in space, as well as by the National Science Foundation and space situational awareness facilities of the United States Space Force.

In addition to finding, tracking, and characterizing NEOs, NASA also researches techniques for deflecting or disrupting, if possible, PHOs that are determined to be on an impact course with Earth to provide options for United States Government response to any detected impact threat. If deflection or disruption of the PHO is not possible due to insufficient time available before impact, the PDCO is responsible for providing expert input to other Government agencies, such as the Federal Emergency Management Agency, for emergency response operations. The PDCO participates in implementing the United States National Near-Earth Object Strategy and Action Plan.

EXPLANATION OF MAJOR CHANGES IN FY 2023

This budget proposes delay of the NEO Surveyor to support other high priority missions within Planetary Science. The Mars Sample Return and Europa Clipper missions are experiencing cost growth and will continue to place pressure on other parts of the Planetary Science portfolio. NASA will continue to use ground and space-based assets to look for NEOs that have any potential to collide with Earth and characterize them to assess if they could do significant damage to our planet.

NEAR EARTH OBJECTS SURVEYOR

Formulation	Development	Operations

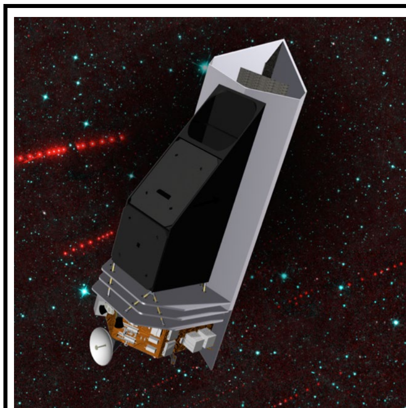
FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**31.3**	**143.2**	**39.9**	**75.0**	**140.0**	**200.0**	**200.0**
Change from FY 2022 Budget Request			**-103.3**				
Percent change from FY 2022 Budget Request			**-72.1%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

PROJECT PURPOSE



The NEO Surveyor spacecraft, shown above, will detect, track, and characterize asteroids and comets moving across the sky against the stationary stars in the background.

The Near-Earth Object Surveyor (NEO Surveyor) addresses NASA's objective to find, track, and characterize the asteroids and comets that could potentially impact Earth and cause significant damage. NEO Surveyor consists of ground and space-based segments that constitute a system searching the sky for significant potential impact hazards. The segments include continued flight operations of the Near-Earth Object Wide-Field Infrared Survey Explorer (NEOWISE) until NASA ends the mission, the NEO Surveyor flight project, and the associated data processing and analysis.

The NEO Surveyor will make significant progress toward the objective given to NASA in Public Law 109-155 Sec. 321, the George E. Brown, Jr. Near-Earth Object Survey Act, which requires detecting, tracking, cataloging at least 90% of NEOs equal to or larger than 140 meters in size, and characterizing a representative subset.

The mission is responsive to the recommendations for planetary defense by the National Academy of Sciences in 2019. The mission also responds to the findings of the National Academy of Sciences report, Defending Planet Earth: Near-Earth Object Surveys & Hazard Mitigation Strategies (2010), and the objectives of the United States National Near-Earth Object Preparedness Strategy and Action Plan (June 2018).

NEO Surveyor will find potentially hazardous objects because of its optimized sensitivity and observation cadence. The mission's primary goals are: (1) identify impact hazards to the Earth posed by NEOs by performing a comprehensive survey of the NEO population; (2) obtain detailed physical characterization data for individual objects that are likely to pose an impact hazard; and (3) advance the understanding of

Formulation	Development	Operations

potential impact energies of potentially hazardous NEOs through characterizing physical properties including object size to inform potential mitigation strategies.

EXPLANATION OF MAJOR CHANGES IN FY 2023

NASA has adjusted the budget profile to support other priorities, which will require the NEO Surveyor team to replan their mission.

PROJECT PRELIMINARY PARAMETERS

NEO Surveyor consists of a single scientific instrument: a 50-centimeter (nearly 20 inch) diameter telescope that operates in two heat-sensing infrared wavelengths. It will be capable of detecting both bright asteroids and dark asteroids - the most difficult type to find.

The NEO Surveyor Observatory will travel in a large-amplitude halo orbit around Sun-Earth Lagrange point 1 (L1). The L1 orbit has the advantages of a flexible launch date and a stable, cold thermal environment that supports passive cooling, and enables high data rates needed to downlink full-frame images for asteroid detection and recovery.

After launch, NEO Surveyor will carry out a five-year baseline survey to find at least two-thirds of the undetected NEOs larger than 140 meters (460 feet). These are the objects large enough to cause major regional damage in the event of an Earth impact. By using two heat-sensitive infrared imaging channels, NEO Surveyor can make accurate measurements of NEO sizes and gain valuable information about their composition, shapes, rotational states, and orbits.

ACHIEVEMENTS IN FY 2021

The project completed Key Decision Point B (KDP-B) in the third quarter of FY 2021 and entered the Phase B preliminary design phase.

WORK IN PROGRESS IN FY 2022

NASA plans to continue work on the NEO Surveyor spacecraft and instrument preliminary designs in FY 2022.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

NASA will continue to make progress toward the project-level Preliminary Design Review (PDR) and KDP-C.

NEAR EARTH OBJECTS SURVEYOR

Formulation	Development	Operations

ESTIMATED PROJECT SCHEDULE

The project will review and determine the new estimated schedule based on funding availability and phasing.

Milestone	Formulation Authorization Document	FY 2023 PB Request
Formulation Authorization	Jun 2020	Jun 2020
SRR-MDR	Oct 2020	Oct 2020
KDP-B	Nov 2020	May 2021
PDR	Feb 2022	Nov 2023
KDP-C	Apr 2022	Feb 2025
CDR	Mar 2023	Nov 2025
KDP-D	Feb 2024	Feb 2027
LRD	Apr 2025	no-earlier-than 2028
EOM	Jun 2030	Oct 2033

Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

Life cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows a non-advocate review and/or preliminary design review.

KDP-B Date	Estimated Life Cycle Cost Range ($M)	Key Milestone	Key Milestone Estimated Date Range
KDP-B May 2021	TBD	LRD	no-earlier-than 2028

Project Management & Commitments

Marshall Space Flight Center (MSFC) Planetary Mission Program Office will provide flight program management. The survey director at the University of Arizona delegated NEO Surveyor project management responsibility to the Jet Propulsion Laboratory (JPL).

NEAR EARTH OBJECTS SURVEYOR

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
NEO Surveyor Director and Investigation Team	NEO Surveyor science and operations leadership	Provider: University of Arizona Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Flight System Management	Project management, systems engineering, safety and mission assurance, and system integration	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
NEO Surveyor Spacecraft	Spacecraft bus with all flight subsystem capabilities	Provider: Ball Aerospace, Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Telescope	50 cm aperture telescope (waveguide and reflectors)	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Camera Assembly Enclosure	Houses the Sensor Chip Assemblies (SCA), Sensor Chip Electronics (SCE), and focal plane modules	Provider: Space Dynamics Laboratory Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Sensor Chip Assemblies (SCA) and Sensor Chip Electronics (SCE)	Digital image sensor and electronics. Two 16 megapixel mercury cadmium telluride focal plane modules	Provider: Teledyne Scientific & Imaging Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Mission Operations	NEOS Spacecraft operations at existing facility with DSN connectivity and existing cybersecurity authorization capability	Provider: Laboratory for Atmospheric Physics (LASP), UC Boulder Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	Yes, trade study performed and LASP selected
NEOS Survey Data System (SDS)	Process, analyze, archive, and distribute NEOS instrument data.	Provider: Caltech IPAC Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

NEAR EARTH OBJECTS SURVEYOR

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
Launch Vehicle	Launch vehicle and all launch services to deliver mission to orbit	Provider: TBD Lead Center: KSC Performing Center(s): KSC Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: The Long-wavelength IR (LWIR) Sensor Chip Assembly (SCA) detector development schedule is delayed, Then: The instrument may fall behind the planned development schedule.	Build, assemble, test, and evaluate flight pathfinder LWIR SCAs during formulation (prior to Phase A). Start SCA procurement early; utilize margin to build additional SCAs.
If: The aperture cover, which protects the instrument's optical surfaces from contamination during ground handling and launch operations, fails to deploy, Then: The observatory will not be able to conduct survey operations.	This is a one-time ejectable aperture cover. The cover uses redundant heritage actuator elements that have flown on Kepler and Spitzer. Phase B design work will incorporate lessons learned from Kepler and will thus have risk considerations and mitigations embedded into the design methodology. Mitigation includes demonstrating flight module full motion test at ambient temperature and first movement deployment at operational temperature (in addition to vacuum), performing design trade to mitigate coefficient of thermal expansion issues, and conducting a finite element analysis to ensure the cover assembly does not generate excessive loads during launch and at cryo-conditions prior to the ejection.

Acquisition Strategy

NASA contracted directly with Caltech/IPAC for the Survey Data System (SDS). JPL will initiate subcontracts for the major flight and ground support components. NASA contracted directly with the University of Arizona (UA) for the survey director, investigation team and associated efforts, and focal planes. UA will initiate subcontracts for the components of the focal plane and deliver those to the flight project.

NEAR EARTH OBJECTS SURVEYOR

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Instrument telescope assembly	Ball Aerospace	Boulder, CO
Survey director, investigation team, and focal planes	University of Arizona	Tucson, AZ
Instrument CEA, CEU, and instrument I&T	Space Dynamics Laboratory (SDL)	Logan, UT
Instrument components, spacecraft bus, and observatory I&T	Ball Aerospace	Boulder, CO

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	Oct 2020	SRB Status Review to assess SRR-MDR results, progress/ resolution of SRR actions, changes since the SRR, and to assess readiness for Phase B	Successful	PDR
Performance	SRB	Nov 2023	PDR	TBD	CDR
Performance	SRB	Nov 2025	CDR	TBD	SIR
Performance	SRB	Jan 2027	SIR	TBD	ORR
Performance	SRB	Feb 2028	ORR	TBD	N/A

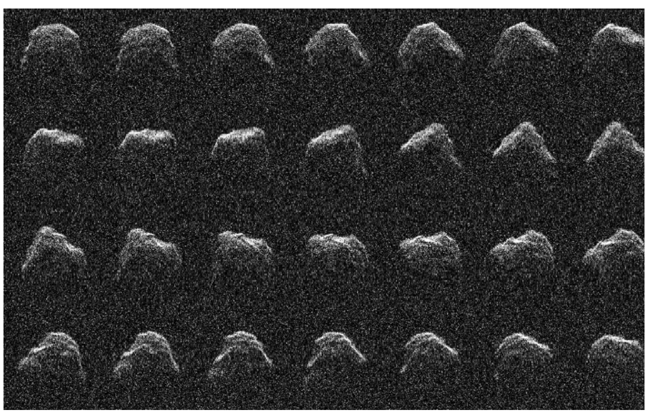
OTHER MISSIONS AND DATA ANALYSIS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Double Asteroid Redirection Test	75.5	16.7	**4.5**	0.0	0.0	0.0	0.0
Near Earth Object Observations	51.3	42.2	**43.3**	41.5	41.5	42.5	47.7
Total Budget	**126.8**	**58.9**	**47.8**	**41.5**	**41.5**	**42.5**	**47.7**
Change from FY 2022 Budget Request			**-11.1**				
Percent change from FY 2022 Budget Request			**-18.8%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



Shown above is a sequence of planetary radar images of asteroid 2016 AJ193 from Goldstone's 70-meter (230 foot) antenna on August 22, 2021, showing one complete rotation. The 1,001st near-Earth asteroid measured by planetary radars since 1968 is three-quarters of a mile (1.3-kilometers) wide. Credit: NASA/JPL-Caltech

Mission Planning and Other Projects

NEAR-EARTH OBJECT OBSERVATIONS (NEOO)

The NEOO project funds work that uses ground and space-based assets to look for Near-Earth Objects (NEOs) that have any potential to collide with Earth and characterizes them to assess if any could do significant damage to our planet. NEOs range in size from a few meters to approximately 34 kilometers. Known NEOs of one kilometer (km) or larger in size are close to 900 in number, while those between 100 meters to one kilometer in size are close to 11,000 in number.

The NEOO project supports a network of activities including search and characterization observatories and the data processing and analysis required to understand the orbits and nature of the near-Earth population of small bodies. In accordance with the findings and recommendations of the National Academies studies on the NEO hazard in 2010 and on visible and infrared NEO survey capabilities in 2019, NASA continues to:

- Analyze the small body data collected by the reactivated Wide-field Infrared Survey Explorer (WISE) mission, now called NEOWISE, and support increased follow-up and analysis of these data;

OTHER MISSIONS AND DATA ANALYSIS

- Increase collection of NEO detection and characterization data by the Catalina Sky Survey, the Panoramic Survey Telescope and Rapid Reporting System (Pan-STARRS), and the United States Space Force's (USSF) Space Surveillance Telescope;
- Support the operation of the four small telescope wide field survey sites called the Asteroid Terrestrial-impact Last Alert System (ATLAS), designed to detect smaller asteroids as they approach the Earth and warn of any imminent impact, two of which will now operate at southern hemisphere sites;
- Support the continued and enhanced operation of planetary radar capabilities at NASA's Goldstone Deep Space Network facility and support the processing and archiving of radar data from the now-decommissioned 305-meter telescope at the National Science Foundation's Arecibo Observatory;
- Utilize NASA's Infrared Telescope Facility for targeted measurement of physical characteristics of NEOs;
- Support NEO research teams at multiple universities and space science institutes to observe and characterize the nature of asteroids and comets which can closely approach Earth; and
- Investigate both ground and space-based concepts for increasing capacity to detect, track, and characterize NEOs of all sizes.

Since NASA's search started in 1998, NEOO research has found over 96 percent of the estimated population of these objects that are one kilometer and larger, and just over 39 percent of all those larger than 140 meters in size. NEOs discovered and characterized by the project may also be viable targets for future robotic and human exploration, and possible eventual candidates for asteroid resource utilization operations.

The Infrared Telescope Facility (IRTF) is NASA's infrared-optimized three-meter telescope site at an altitude of 13,600 feet on the extinct volcano Mauna Kea on the Big Island of Hawai'i. The NEOO project funds IRTF operations and IRTF is a primary NASA planetary defense asset for NEO physical characterization. IRTF continues its mission of strategic support of NASA flight missions and science goals in both planetary science and astrophysics while being on-call for rapid response observations of NEO targets of opportunity and potential threats.

The NEOWISE mission uses the WISE spacecraft, a 40-centimeter (16-inch) diameter infrared telescope in Earth orbit that continues an all-sky astronomical survey with its two detectors, which remain in non-cryogenic operations. NEOWISE capabilities and vantage point enable contribution to NEO discovery and, more significantly, understanding the physical properties of large numbers of NEOs, comets, main-belt asteroids, and other minor planets.

Recent Achievements

In FY 2021, asteroid search teams funded by the NEO Observations project found another five near-Earth asteroids (NEAs) larger than one kilometer in size with orbits that come close to Earth's vicinity. Asteroid search teams also found 3,025 NEAs less than one km in size and observers found three additional Earth-approaching comets, bringing the total known population of NEOs to 26,968 NEAs and 117 Earth-approaching comets as of September 30, 2021. The high-precision orbit predictions computed by the Center for Near-Earth Object Studies at JPL show that none of these objects are likely to strike the Earth in the next century. However, as of January 2022, there are 2,240 near-Earth asteroids (of which 160 are

OTHER MISSIONS AND DATA ANALYSIS

larger than one km in diameter) with 95 found in FY 2021, in orbits that could become a hazard in the more distant future and warrant continued monitoring.

Researchers studied asteroids in detail during their close approaches to Earth, characterizing small or potentially hazardous asteroids and yielding important new near-Earth asteroid discoveries. During FY 2021, they observed 131 asteroids passing Earth within the distance to our Moon. Most of the asteroids were less than 50 meters in size and all but one passed in the days either just prior to or just following their closest approach to the Earth. Ten of the smaller asteroids (less than 13 meters in size) passed within the distance of the orbiting geosynchronous satellites.

WORK IN PROGRESS FY 2022

The NEOWISE spacecraft orbit has been moving away from the ideal Sun synchronous orbit alignment since the end of prime operations in 2010. In FY 2022, it will complete its ninth year of operations since reactivation and engineers will continue to closely monitor the temperature on the spacecraft. Excessive heat would effectively blind the infrared detectors, terminating the useful life of the spacecraft. NEOWISE has no orbital maintenance thrust capability, therefore it cannot compensate for this natural orbital movement.

The USSF Space Surveillance Telescope is in the process of test and commissioning in Australia. NASA continues to coordinate with USSF Space Command on a logistical and funding path for transferring the data from Australia to the United States. Researchers will use the USSF data for asteroid detection and tracking. The Lincoln Near-Earth Asteroid Research team continues to prepare the data processing pipeline for the data.

The Asteroid Terrestrial-impact Last Alert System (ATLAS) team is completing development of the two new ATLAS observatory stations in South Africa and Chile and will commission the sites and begin southern hemisphere NEO survey operations.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

NASA will continue to support a network of search and characterization observatories and the data processing and analysis required to understand the near-Earth population of small bodies and detect any threats for impacting Earth.

Operating Missions

DOUBLE ASTEROID REDIRECTION TEST (DART)

The Double Asteroid Redirection Test (DART) is the first planetary defense mission demonstrating the kinetic impact technique to change the motion of an asteroid in space. The target asteroid for DART is the binary asteroid system Didymos. The Didymos system consists of the primary asteroid, Didymos A, which is about 780 meters (1/2 mile) across, and a “moonlet,” Dimorphos. The DART spacecraft will demonstrate the kinetic impact deflection method by deliberately crashing into Dimorphos at a speed of approximately 15,000 miles per hour, with the aid of an onboard camera and sophisticated autonomous

OTHER MISSIONS AND DATA ANALYSIS

navigation software. The collision will change the period of the orbit of the moonlet around the main body by a fraction of one percent, but enough to measure from telescopes on Earth. By targeting the small moonlet in a binary system, the DART mission plan makes this demonstration possible without causing any detectable change to the orbit of the system about the Sun. The DART mission will demonstrate the effectiveness of the kinetic impact technique for deflecting a hazardous asteroid. NASA will use the mission to improve our understanding of the physics involved and our readiness to respond to an actual asteroid impact threat.

NASA's DART spacecraft launched on November 24, 2021. The targeted impact date with Dimorphos is September 26, 2022, when the Didymos system is within 11 million kilometers of Earth, enabling subsequent observations of the change to the orbital period of the moonlet by ground-based telescopes.

Recent Achievements

After DART completed integration and test activities, comprehensive mission readiness tests, the pre-ship readiness review, and the preparations to ship the spacecraft to the launch site, NASA successfully launched DART aboard a Falcon 9 Rocket on November 24, 2021 from Vandenberg Space Force Base.

WORK IN PROGRESS IN FY 2022

The DART spacecraft has launched and will complete its on-orbit checkout activities prior to entry into Phase E mission operations. The spacecraft will spend most of FY 2022 in cruise to the targeted Didymos system, beginning terminal approach operations in September 2022 for an impact with Dimorphos on September 26, 2022.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

In the final year of the mission, following the DART impact with Dimorphos, the mission investigation team will complete telescopic observations of the Didymos asteroid system to characterize the change in orbit of the moonlet caused by the impact, conduct post-impact data analysis and modelling, and prepare the final close-out report to document the mission's success.

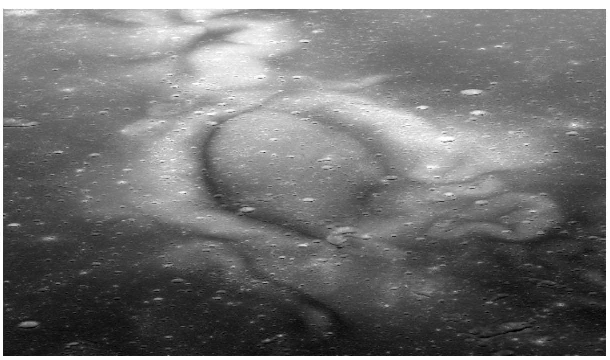
LUNAR DISCOVERY AND EXPLORATION

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
VIPER	99.1	112.2	**97.0**	30.6	0.0	0.0	0.0
Other Missions and Data Analysis	344.4	385.0	**389.3**	427.7	458.3	458.3	468.3
Total Budget	**443.5**	**497.3**	**486.3**	**458.3**	**458.3**	**458.3**	**468.3**
Change from FY 2022 Budget Request			**-11.0**				
Percent change from FY 2022 Budget Request			**-2.2%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



Shown here is an LRO Narrow Angle Camera oblique image looking west to east over the Reiner Gamma Formation (7.409°N, 300.972°E, north is to the left). The mysterious "swirl" is the target of the Lunar Vertex payload selected through PRISM-1 for delivery by CLPS [NASA/GSFC/Arizona State University].

NASA's exploration strategy will provide an innovative and sustainable approach to scientific and human exploration, with commercial and international collaborators to enable human expansion across the solar system and bring new knowledge and opportunities back to Earth. The Agency will achieve these accomplishments with emerging commercial capabilities and innovative approaches to achieving human and science exploration goals, including the return of humans to the Moon.

The Lunar Discovery and Exploration Program (LDEP) in the Science Mission Directorate is a key component of the Agency's exploration strategy. LDEP establishes commercial contracts for lunar payload delivery and other related services through the Commercial Lunar Payload Services (CLPS) initiative; continues operations of the Lunar Reconnaissance Orbiter (LRO); and developing SmallSats, instruments, and other payloads that serve lunar science, long-term exploration, and utilization needs. LDEP will provide innovative investigations to enhance lunar exploration and science by developing technical capabilities and increased commercialization for an expanded range of lunar services. NASA is prioritizing capabilities that support lunar resource analysis and prospecting to inform future human space flight objectives. For example, LDEP will focus on instrumentation to advance knowledge and technologies for the use of local resources, such as lunar water ice. Working with the science and human exploration communities, our international partners, and United States industry, NASA will refine the goals and objectives for a robust and sustainable lunar exploration and science program.

In collaboration with private industry and the scientific community, the program is developing lunar surface payloads (and supporting orbital payloads) along with cost-effective ways to deliver and provide services for these payloads. These payloads and services address the Nation's lunar exploration, science,

LUNAR DISCOVERY AND EXPLORATION

and technology demonstration goals. The National Academies of Sciences 2011 Decadal Survey highlight these goals: Vision and Voyages for Planetary Sciences in the Decade 2013-2022.

NASA purchases commercial transportation/delivery services to the Moon for NASA instruments and technology demonstration payloads. These transportation or delivery services include needed "utilities" from the commercial systems, such as power, communications, and thermal control, during launch integration, launch, and cruise phase, and in most cases, operations at the lunar destination. In other cases, these services culminate in deployment of a NASA asset such as a rover to fulfill its own mission. In addition, NASA will pursue the purchase of science or engineering data provided by contractor systems, as well as the possibility of returning payloads and/or samples to the Earth. LDEP also makes these commercial lunar services available to other NASA mission directorates.

EXPLANATION OF MAJOR CHANGES IN FY 2023

NASA has established two new projects within this program: the Payloads and Research Investigations on the Surface of the Moon-2 (PRISM-2) project, which will support the second round of PRISM selections scheduled for FY 2022; and the Lunar Science project, which includes science planning support for Artemis architecture formulation.

ACHIEVEMENTS IN FY 2021

Final development of CLPS early-delivery payloads continued in FY 2021. NASA used the new PRISM initiative to solicit and award three Principal Investigator (PI)-led payload suites for two CLPS deliveries. Lunar Trailblazer completed its PDR in October 2020 and CDR in July 2021. NASA awarded a CLPS task order to deliver the Polar Resources Ice Mining Experiment-1 (PRIME-1) drill experiment to the lunar south pole in FY 2023 and awarded another task order for delivery of seven payloads to Crisium Basin, bringing the total number of active CLPS lunar deliveries to six.

NASA continued to engage with the science community, NASA’s international exploration partners, and United States industry to refine the exploration, scientific, and technology objectives in support of LDEP.

NASA sustained LRO operations in support of scientific research and future science and exploration mission planning. NASA will provide LRO landing site characterization capabilities to international partners for future lunar lander missions when requested.

WORK IN PROGRESS IN FY 2022

In FY 2022, NASA plans to make two more CLPS awards. The first two CLPS deliveries to the lunar surface will occur in late CY 2022.

NASA will also competitively select additional robotic lunar surface payloads through the PRISM-2 solicitation and deliver the instruments to the Moon in the 2025 timeframe via CLPS-provided landing services.

The VIPER rover completed its critical design review.

The DALI solicitation was released in February 2022.

LUNAR DISCOVERY AND EXPLORATION

Lunar Trailblazer will complete its System Integration Review in May 2022 and the team will prepare to place the spacecraft into storage.

NASA will competitively select additional robotic lunar surface payloads through the PRISM-2 solicitation to fly on CLPS-provided launch and landing services to the lunar surface in the CY 2025 timeframe.

NASA will release a competitive solicitation for potential Artemis in-situ/deployed science instruments, as well as instruments that will ride with or on NASA's Lunar Terrain Vehicle (LTV). The Exploration Systems Development Mission Directorate is developing LTV for the Artemis Program. LTV is a human-rated, unpressurized (unenclosed) rover that will help astronauts explore and conduct experiments on the lunar surface.

LRO remains in extended operations and continues to offer LRO landing site characterization capabilities to international and commercial stakeholders upon request.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

NASA will release a competitive solicitation for potential Artemis in-situ/deployed science instruments as well as instruments that will ride with or on NASA's Lunar Terrain Vehicle (LTV).

Two LDEP CLPS deliveries will take place in FY 2023 along with instruments from the Space Technology Mission Directorate (STMD) and Space Operations Mission Directorate (SOMD). CLPS will launch STMD's Polar Resources Ice Mining Experiment-1 between the November 2022 and January 2023 timeframe. The second delivery will be STMD's Electrostatic Dust Shield experiment, as well as SOMD's Lunar Global Navigation Satellite System Receiver Experiment in September 2023. NASA will continue to competitively select additional robotic lunar surface payloads through the PRISM solicitation and expects to continue its two-per year minimum cadence of delivery awards.

Lunar Trailblazer will go into storage in October 2022 where it will await integration and launch with its rideshare, the Interstellar Mapping and Acceleration Probe mission, which will launch no earlier than February 2025.

NASA will complete instrument selections and science awards of deployed instruments for the first Artemis human landing (including the core geology team and analog activities and science support), DALI selections and awards and the PRISM-3 solicitation to the community.

Program Schedule

Date	Significant Event
Oct 2021	VIPER CDR
Feb 2022	Released DALI solicitation
May 2022	Lunar Trailblazer SIR
Q1 FY 2023	Scheduled* delivery of payloads by Intuitive Machines through CLPS
Q1 FY 2023	Scheduled* delivery of payloads by Astrobotic through CLPS

LUNAR DISCOVERY AND EXPLORATION

Date	Significant Event
Q1 FY 2023	Deliver NASA-funded LSITP payloads for integration into CLPS deliveries to the lunar surface
Q2 FY 2023	Release PRISM-3 solicitation to the community
Jul 2023	Deliver VIPER to Astrobotic for delivery to lunar south polar region
Q3 FY 2023	Artemis In-situ/Deployed Instruments Selections and Awards
Q4 FY 2023	Scheduled* delivery of PRIME-1 drill to southern lunar pole region by Intuitive Machines
Q4 FY 2023	LTV Instruments Selections and Awards
Q1 FY 2024	Scheduled* delivery of payloads to lunar south polar region by Masten
Q3 FY 2024	Scheduled* delivery of payloads to Crisium Basin by Firefly Aerospace through CLPS

**NASA does not manage the launch vehicle portion of the CLPS effort and does not ultimately control final launch schedules of the selected providers that will deliver NASA and other provider-provided payloads. NASA will work with the CLPS vendors to ensure timely and successful launch and delivery of all science and technology payloads.*

Program Management & Commitments

The Planetary Mission Program Office located at Marshall Space Flight Center is responsible for managing the LRO and Lunar Trailblazer missions, as well as Lunar Surface Instrument and Technology Payloads (LSITP) and PRISM instruments.

NASA Headquarters (HQ) Planetary Science Division and Ames Research Center manage the VIPER mission. NASA HQ and Johnson Space Center manage the CLPS initiative.

Program Element	Provider
Lunar Reconnaissance Orbiter	Provider: Goddard Space Flight Center (GSFC) Lead Center: GSFC Performing Center(s): GSFC, Jet Propulsion Laboratory (JPL) Cost Share Partner(s): N/A
Lunar Instruments	Provider: Various Lead Center: HQ Performing Center(s): N/A Cost Share Partner(s): N/A
Commercial Lunar Payload Services	Provider: Various Lead Center: JSC Performing Center(s): N/A Cost Share Partner(s): N/A

LUNAR DISCOVERY AND EXPLORATION

Program Element	Provider
VIPER	Provider: Ames Research Center (ARC) Lead Center: ARC Performing Center(s): ARC, JSC, KSC Cost Share Partner(s): N/A
DALI	Provider: Various Lead Center: Headquarters Performing Center(s): ARC, GRC, GSFC Cost Share Partner(s): N/A
PRISM-1	Provider: JPL, APL Lead Center: HQ Performing Center(s): JPL and MSFC Cost Share Partner(s): N/A
Lunar Trailblazer	Provider: JPL Lead Center: HQ Performing Center(s): JPL Cost Share Partner(s): N/A
Lunar Management	Provider: HQ, MSFC Lead Center: HQ Performing Center(s): MSFC Cost Share Partner(s): N/A
PRISM-2	Provider: TBD Lead Center: HQ Performing Center(s): TBD Cost Share Partner(s): N/A
Lunar Science	Provider: Various Lead Center: HQ Performing Center(s): Various Cost Share Partner(s): N/A

Acquisition Strategy

LDEP uses flexible contract mechanisms, such as indefinite-delivery-infinite-quantity (IDIQ) contracts, to enable the flexible and rapid procurement of commercial transportation services to deliver NASA scientific, exploration, and technology development payloads to the surface of the Moon, and potentially to lunar orbit. NASA may expand lunar service requirements to include more capabilities, such as mobility or sample return.

In parallel, NASA uses its established solicitation mechanisms, such as the Research Opportunities in Space and Earth Science (ROSES), NASA Research Announcements (NRA) and the Stand Alone

LUNAR DISCOVERY AND EXPLORATION

Missions of Opportunity Notice (SALMON) AO processes, to select and develop exploration, scientific, and technology development payloads for delivery to the Moon. In some cases, NASA may direct a NASA center to develop a lunar capability or surface payload when it is in the Government's best interest, such as when that capability supports multiple NASA applications or when a commercial entity or international stakeholder identifies a near-term opportunity for a lunar surface mission on a timeframe that does not support competitive selection. However, to the maximum extent possible, NASA will leverage commercial efforts.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Commercial Lunar Payload Services (2)	Astrobotic Technology	Pittsburgh, PA
Commercial Lunar Payload Services (2)	Intuitive Machines	Houston, TX
Commercial Lunar Payload Services	Firefly Aerospace	Cedar Park, TX
Lunar Trailblazer	California Institute of Technology	Pasadena, CA
Commercial Lunar Payload Services	Masten Space Systems	Mojave, CA

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

FY 2023 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027	BTC	Total
Formulation	80.1	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	80.1
Development/Implementation	14.5	99.1	112.2	**97.0**	13.5	0.0	0.0	0.0	0.0	336.2
Operations/Close-out	0.0	0.0	0.0	**0.0**	17.2	0.0	0.0	0.0	0.0	17.2
2022 MPAR LCC Estimate	**94.6**	**99.1**	**112.2**	**97.0**	**30.6**	**0.0**	**0.0**	**0.0**	**0.0**	**433.5**
Total Budget	**94.6**	**99.1**	**112.2**	**97.0**	**30.6**	**0.0**	**0.0**	**0.0**	**0.0**	**433.5**
Change from FY 2022 Budget Request				**-15.2**						
Percent change from FY 2022 Budget Request				**-13.5%**						

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The 2022 MPAR LCC Estimate reflects the Fiscal Year 2022 Quarter 1 Financial Report, which is current as of December 2021. The requested budget authority is the project's current budget requirements which have seen programmatic changes approved by NASA since December 2021.

Shown here is the VIPER Rover in motion performing obstacle testing at NASA-GRC.

PROJECT PURPOSE

The Volatiles Investigating Polar Exploration Rover (VIPER) is a robotic lunar rover that will explore the relatively nearby, but extreme environment of the Moon, in search of water ice and other potential volatile resources. The suite of instruments will also address high priority science questions by providing information about the origin and distribution of water on the Moon and across the solar system. NASA will use the data the rover collects to determine where the Moon's water ice is most likely to be found and easiest to access, making VIPER the first-ever resource mapping mission on another celestial body. NASA can then use these maps to aid in the decision process for future lunar

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

human space exploration, and beyond. The first water maps of the Moon will mark a critical step forward in NASA's Artemis Program to establish a sustainable human presence on the surface of the Moon.

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

PROJECT PARAMETERS

VIPER will operate for approximately 100 Earth-days to cover three cycles of lunar day/night near the western edge of Nobile Crater in the lunar South Pole region, with a scheduled FY 2024 arrival. VIPER is a remotely commanded golf-cart sized rover that will be delivered onto the Moon's surface via CLPS provided services. The CLPS delivery task order awardee provides all services required to deliver NASA equipment to the Moon's surface, such as the launch, lander system, and lander operations. The CLPS initiative funds all costs associated with the delivery task order.

VIPER will explore the Nobile Crater area and will venture into some of the semi-permanent and permanently shadowed regions of the Lunar South Pole to survey different ice-stability regions to detect and assess volatiles distributions and concentrations. To achieve its scientific goals, the rover will carry four instruments including a one-meter drill. Collectively, the instrument set will be used to detect and analyze various lunar soil environments at a range of different depths and temperatures.

The VIPER drill, The Regolith and Ice Drill for Exploring New Terrain (TRIDENT), will excavate using the auger/percussion approach, which utilizes a hammering action in conjunction with a rotary motion, to extract down to a depth of 1-meter and deliver lunar regolith in small (10 centimeter) segments for vertical profiling.

The Neutron Spectrometer System (NSS) instrument will prospect for and map the distribution of hydrogen-rich materials while roving. NSS will be located on the front of the rover to have an unobstructed view of the lunar surface.

The Near InfraRed Volatiles Spectrometer System (NIRVSS) instrument will operate during roving or while drilling. The instrument will look for near real-time changes in the properties of the materials exposed. Using different wavelengths of light to illuminate the surface, the team will use NIRVSS to provide an additional means of surveying the surface and immediate excavation site for water and other volatiles, providing surface and regolith mineral context.

The Mass Spectrometer observing lunar operations (MSolo) instrument will operate during roving or while drilling. MSolo will identify low-molecular weight volatiles on the surface or from subsurface excavations. Working in concert with the NIRVSS instrument, the instruments will analyze volatiles from the materials delivered by the drill bit from a depth of up to one meter.

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

ACHIEVEMENTS IN FY 2021

The project conducted a successful KDP-C in February 2021 and entered the design and fabrication phase.

The team further defined and advanced work on interface requirements with the VIPER CLPS provider, Astrobotic, that will inform the lander/launch vehicle development and payload accommodation approach. Astrobotic selected SpaceX's Falcon Heavy rocket as the launch vehicle to deliver the Griffin lunar lander which will be carrying VIPER to the Moon in FY 2024. On September 21, 2021 NASA announced that Nobile Crater will be VIPER's landing site, in the Lunar South Pole region.

WORK IN PROGRESS IN FY 2022

The VIPER project successfully completed its CDR in October 2021. The System Integration Review (SIR) and Key Decision Point-D (KDP-D) will take place in the summer of 2022. A successful KDP-D will mark VIPER's transition into the system assembly, integration, and test phase of development.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

VIPER will conduct its Pre-Ship Review in the summer of 2023 and then ship the completed rover to the CLPS provider. After integration with the Griffin lander, it will arrive at Kennedy Space Center and prepare for launch.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2023 PB Request
KDP-C	Feb 2021	Mar 2021
CDR	Nov 2021	Oct 2021
SIR	May 2022	Jun 2022
PSR/Ship to CLPS Provider	Jul 2023	Jul 2023
Launch Readiness	Nov 2023	Nov 2023
Initial Operational Capability	Nov 2023	Nov 2023

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

Development Cost and Schedule

The confidence level developed for VIPER confirmation is the result of a combination of analysis between an independent cost estimate and an independent schedule estimate.

Base Year	Base Year Develop-ment Cost Estimate ($M)	CL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2021	336.2	70	2022	336.2	-	IOC	Nov 2023	Nov 2023	-

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

The CLPS project funds all costs associated with launch and landing. Launch vehicle costs reported here are for VIPER integration requirements.

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**336.2**	**336.2**	**0**
Rover	92.2	119.4	+27.2
Payloads	22.8	23.2	+0.4
Systems I&T	15.7	19.6	+3.9
Launch Vehicle	1.8	1.7	-0.1
Ground Systems	37.1	38.6	+1.5
Science/Technology	7.2	7.2	0
Other Direct Project Costs	159.4	126.5	-32.9

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

Project Management & Commitments

Ames Research Center (ARC) manages the VIPER mission and provides systems engineering, project science, real-time rover surface operations, and flight software.

Element	Description	Provider Details	Change from Baseline
Project Office and Mission Management including Science, System Engineering, Safety & Mission Assurance	Overall mission planning and project management functions.	Provider: NASA Lead Center: ARC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Rover	A mobility and power platform hosting the VIPER instrument set, communication system, navigation, and other vehicular sub-systems for use to traverse the lunar surface.	Provider: NASA Lead Center: ARC Performing Center(s): JSC Cost Share Partner(s): N/A	N/A
TRIDENT	A percussion drilling instrument with force, displacement, and thermal sensors.	Provider: Honeybee Robotics Lead Center: ARC Performing Center(s): KSC Cost Share Partner(s): N/A	N/A
NSS	Neutron Spectrometer instrument	Provider: NASA Lead Center: ARC Performing Center(s): ARC Cost Share Partner(s): N/A	N/A
NIRVSS	Near infrared spectrometer instrument	Provider: NASA Lead Center: ARC Performing Center(s): ARC Cost Share Partner(s): N/A	N/A
MSolo	Mass spectrometer instrument	Provider: NASA Lead Center: ARC Performing Center(s): KSC Cost Share Partner(s): N/A	N/A

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Lander and Launch Vehicle	CLPS-provided lander and launch vehicle (not included in VIPER baseline)	Provider: Astrobotic Lead Center: JSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: VIPER is required to make unexpected design changes to enable payload accommodation with the CLPS vendor, Then: This could increase its life cycle cost and schedule.	The VIPER project, CLPS office staff, and Astrobotic are in regular contact to develop interface requirements while maximizing system success. VIPER has secured additional mass allocation on the Astrobotic vehicle which will help mitigate any risk of mass growth on the VIPER mission.

Acquisition Strategy

NASA is designing, developing, building, integrating, and testing most of the elements of VIPER at NASA centers. The VIPER rover at Johnson Space Center (JSC), the NSS and NIRVSS instruments at ARC, and MSolo at Kennedy Space Center (KSC) are all NASA in-house developments. The TRIDENT drill was competed and awarded to Honeybee Robotics.

NASA awarded a CLPS delivery task order contract to Astrobotic Technology Inc. of Pittsburgh, Pennsylvania to deliver VIPER to the Moon in late 2023. The current contract value is $235.7M. In a CLPS delivery task order, the company provides all services required to deliver NASA equipment to the Moon's surface such as the launch, lander system and lander operations. The CLPS initiative funds all costs associated with the delivery task order.

MAJOR CONTRACTS/AWARDS

None.

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

INDEPENDENT REVIEWS

The VIPER Review Team (VRT) is an independent review team tasked to complete key life cycle reviews for VIPER, as well as to engage the project team with more frequent, less formal, and more mentoring interactions.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	VRT	Oct 2021	Critical Design Review	Passed	SIR
Performance	VRT	Jun 2022	Systems Integration Review	TBD	ORR

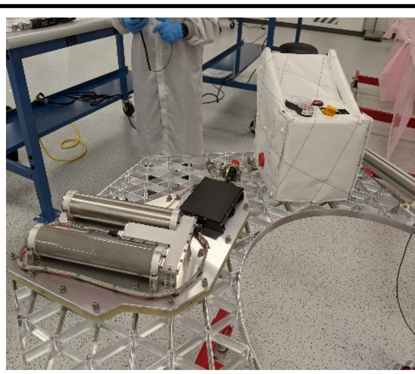
OTHER MISSIONS AND DATA ANALYSIS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Payloads and RI on Surface of the Moon-2	0.0	15.0	**25.0**	15.0	5.0	0.0	0.0
Development and Advancement of Lunar Ins	20.5	15.1	**14.3**	15.0	15.0	15.0	15.0
Lunar Trailblazer	23.2	17.5	**1.2**	4.3	3.4	1.8	0.8
Payloads and RI on Surface of Moon-1	21.0	25.5	**21.5**	8.5	0.0	0.0	0.0
Lunar Future	2.9	3.6	**5.9**	5.7	35.1	44.5	57.0
Lunar Instruments	16.4	23.6	**31.8**	82.9	105.4	102.5	96.5
Commercial Lunar Payload Services	233.4	254.0	**255.3**	254.4	254.4	254.4	254.5
Lunar Intl Mission Collaborations	0.7	0.5	**0.5**	0.5	0.5	0.5	0.5
Lunar Management	4.2	5.9	**6.0**	9.8	4.5	4.5	4.6
Lunar Reconnaissance Orbiter (LRO)	22.2	22.1	**22.0**	22.0	22.0	22.0	22.0
Lunar Science	0.0	2.2	**5.7**	9.5	12.9	13.1	17.6
Total Budget	**344.4**	**385.0**	**389.3**	**427.7**	**458.3**	**458.3**	**468.3**
Change from FY 2022 Budget Request			**4.3**				
Percent change from FY 2022 Budget Request			**1.1%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



Shown here are the lunar instruments Neutron Spectrometer System (left) and Near-Infrared Volatiles Spectrometer System (right) installed onto the payload deck of a CLPS lunar lander.

Mission Planning and Other Projects

Other Missions and Data Analysis includes mission planning, small missions in development, instrument and technology development, operating missions, international collaborations, management activities, and funding for future instrument and mission selections.

DEVELOPMENT AND ADVANCEMENT OF LUNAR INSTRUMENTATION (DALI)

DALI focuses on advancing the development of spacecraft-based instruments that show promise for use in future lunar missions including expected commercial ventures. DALI activities develop and demonstrate lunar science instruments to the point where principal investigators may propose their use in response to future announcements of flight opportunity without additional extensive technology development. DALI focuses on instruments with technology readiness levels (TRLs) four through six.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

NASA released the DALI 2022 NRA in February 2022 and expects to make five selections. To date, NASA has awarded 25 DALI technology development efforts.

LUNAR TRAILBLAZER

NASA selected a SmallSat called Lunar Trailblazer from a Small Innovative Missions for Planetary Exploration (SIMPLEx) call. Trailblazer will spend one year orbiting the Moon at an altitude of 100 kilometers to generate a high-resolution map, at 100 meters per pixel, that charts the form, abundance, and distribution of water while also collecting information about the environments where that water exists, including within shadowed craters. Lunar Trailblazer will carry two instruments: a shortwave imaging spectrometer to search for the signature of water, either in the form of ice or bound to minerals; and a multispectral thermal imager to map the temperature, physical properties, and composition of regions where the spectrometer detects water. These data will fill in gaps of our understanding of the distribution and composition of lunar volatiles as well as contribute to mission planning for future human exploration.

Recent Achievements

Lunar Trailblazer passed its Critical Design Review (CDR) in July 2021 and continued to make progress in final design and fabrication, which will continue in FY 2022. Lunar Trailblazer is a rideshare on the Interstellar Mapping and Acceleration Probe (IMAP) mission, launching no earlier than February 2025 on a SpaceX Falcon 9 rocket.

PAYLOADS AND RESEARCH INVESTIGATIONS ON THE SURFACE OF THE MOON (PRISM) - 1

As the NASA Provided Lunar Payloads (NPLP) and Lunar Surface Instrument and Technology Payloads (LSITP) instruments are completed, the PRISM instrument selections will continue to help NASA develop science-driven payloads for manifesting on future CLPS deliveries and on international flight opportunities. PRISM calls are for investigations utilizing suites of instruments (as opposed to individual payloads acquired under NPLP and LSITP) manifested on CLPS deliveries. The PRISM-1 selections will launch to two high science-value locations with deliveries to the lunar surface expected as early as December 2023: the Reiner Gamma albedo swirl on the lunar nearside and the Schrödinger Basin on the lunar far side. This innovative approach for soliciting science investigations and technology demonstration payloads for future deliveries by CLPS providers will enable decadal-caliber science at the Moon and support the Artemis campaign.

Recent Achievements

NASA made PRISM-1 selections in June of 2021. Lunar Vertex is a joint lander and rover payload that will make detailed surface measurements of the Moon's magnetic field using an onboard magnetometer to better understand lunar swirls. Lunar swirls are associated with magnetic field anomalies on the lunar surface and exhibit regions of decreased space weathering of the lunar soils. Lunar Vertex will help determine the origin of lunar swirls, their impact on space weathering rates, and the plasma environment associated with the solar wind in the presence of magnetic fields. The Farside Seismic Suite (FSS) will

OTHER MISSIONS AND DATA ANALYSIS

return the Agency's first seismic data from the far side of the Moon, which will help determine the near-field crustal features, as well as the deep lunar interior structure. FSS will also employ small-scale "survive the lunar night" technology to last for several lunar days (three or more Earth months) and make long-duration observations of the lunar interior. The second payload suite to Schrodinger Basin is the Lunar Interior Temperature and Materials Suite that will provide an in-depth look at the Moon's internal structure through magnetotellurics coupled to a heat flow probe. Both datasets will complement the seismic data acquired by the FSS to tell a more complete geophysical story of the current state of the lunar interior. Magnetotellurics is an electromagnetic geophysical method for inferring a planetary body's subsurface electrical conductivity, and thus geologic structure, from measurements of natural geomagnetic and geoelectric field variation at the planetary body's surface.

LUNAR FUTURE

Lunar Future supports future activities, studies, instruments, and missions with a strategic focus that helps NASA achieve human and science exploration goals, including the return of humans to the Moon. Apollo Next Generation Sample Analysis (ANGSA) research selections began in 2019 and continues through FY 2022. Funding for future ANGSA selections is in the Lunar Science research line.

Recent Achievements

The ANGSA initiative continued to provide new perspectives on: (1) the sources, formation, and evolution of lunar volatile reservoirs; (2) characteristics, triggers, and chronology of processes shaping the Moon; and (3) the magmatic, volatile, thermal, and impact history of the Moon based on new lunar lithologies. The results of this initiative are providing a fundamental reference point for the Artemis campaign and future lunar exploration.

LUNAR INSTRUMENTS

NASA is developing instruments and technology payloads to manifest on both CLPS deliveries, Artemis crewed missions, and international lunar lander missions. These instruments come from United States academia and industry, as well as from NASA centers. These activities include NASA Provided Lunar Payloads (NPLP) and Lunar Surface Instrument and Technology Payloads (LSITP) NPLP and LSITP, which NASA has manifested on CLPS deliveries to launch by 2025. This project also includes funding for future PRISM and Artemis instrument selections.

Recent Achievements

NASA is progressing with the development and delivery of payloads awarded in February and May of 2019. The 12 internally-developed NPLP payloads are all complete and delivered to CLPS providers for integration into their delivery systems. The 12 academic- and industry- developed LSITP payloads are generally on-track for their planned CLPS deliveries to the surface of the Moon. NASA is also collaborating with the Canadian Space Agency (CSA) to provide a United States instrument for a CSA lunar rover, which CLPS will deliver to the Moon.

OTHER MISSIONS AND DATA ANALYSIS

COMMERCIAL LUNAR PAYLOAD SERVICES (CLPS)

CLPS is opening competition to United States commercial providers of space transportation services, with the strategic goal of supporting affordable commercial operations on and near the Moon, consistent with the National Space Transportation Policy and Commercial Space Act. CLPS consists of a multi-vendor catalog, a 10-year indefinite-delivery-indefinite-quantity (IDIQ) contract. NASA manages this effort through task order competitions for specific lunar surface transportation services of payloads with NASA being one of several customers. NASA also collaborates with international partners on CLPS by manifesting international payloads on CLPS landers in exchange for rights to the data and placement of United States scientists on the international science teams.

Recent Achievements

CLPS now has six commercial deliveries actively in work that will all occur between FY 2022 and FY 2024. These commercial missions are also delivering payloads provided by customers other than NASA. See the list of commercial service company awardees in the Major Contract/Awards table of the Lunar Discovery and Exploration Program section. A seventh commercial delivery is in the acquisition cycle. NASA is also planning to partner with the European Space Agency (ESA) to fly two payloads via CLPS to the lunar surface: a large Lunar Retroreflector for Earth-based laser ranging; and a volatiles characterization payload to fly to the lunar south polar region. In November 2021 NASA selected Intuitive Machines to deliver science investigations and a technology demonstration to the Reiner Gamma lunar swirl on the western edge of the Moon's surface. The four payloads are: the Korea Astronomy and Space Science Institute radiation sensor payload, Lunar Space Environment Monitor; JPL's Cooperative Autonomous Distributed Robotic Exploration mobile robots; the European Space Agency laser, MoonLIGHT retroreflector; and Lunar Vertex, which was one of the PRISM selections.

LUNAR INTERNATIONAL MISSION COLLABORATION

In developing collaborations with our international partners, NASA funds United States participating science investigators and provides international collaborators with lunar landing site characterization data, as well as navigation and data relay services, in exchange for United States participation. Participation includes establishing United States scientists on the international instrument team, access to data returned from the mission, and assurance that participating scientists will publicly archive returned data in a manner consistent with NASA policies. NASA is also providing science instruments to fly on international missions.

Recent Achievements

NASA finalized agreements to provide contributions to two Japan Aerospace Exploration Agency (JAXA) missions: a small Laser Retroreflector Array for lunar orbital ranging and DSN support for the JAXA Smart Lander for Investigating Moon; and a Neutron Spectrometer on the Lunar Polar Exploration mission rover system, which the Indian Space Research Organization will deliver to the lunar surface.

LUNAR MANAGEMENT

The Planetary Missions Program Office (PMPO) at the Marshall Space Flight Center manages Planetary Science flight projects that are not part of the Mars Exploration Program, including certain elements of

OTHER MISSIONS AND DATA ANALYSIS

the LDEP portfolio, such as the contracts selected through LSITP for lunar delivery by CLPS landers, PRISM awards, LRO, and the Lunar Trailblazer mission. PMPO provides programmatic, technical, and business management of these LDEP activities. Lunar Management also includes support for review boards, external technical support as needed and future mission studies.

LUNAR SCIENCE

NASA is maximizing the lunar science achieved in this era of lunar exploration through science planning support for Artemis architecture formulation, including science support for tool development and astronaut geology training. This project also supports Artemis-specific curation activities to prepare for the return of new lunar samples, including samples containing volatiles and those requiring cold curation. It also supports surface operations development, including analog activities to help NASA define and develop a real-time science support room structure and science team integration. In addition, targeted research and analysis funding will prepare and enable the lunar community to take maximum advantage of data and samples from Artemis and CLPS.

Recent Achievements

The Contamination and Research Integrity (CaRI) rapid response team is providing science support and guidance as NASA develops the systems and hardware for the Artemis campaign. They deliver timely input on a range of science issues in response to questions from across Artemis on topics from allowable materials for tools and containers, to camera specifications, and cold curation requirements.

PRISM-2

PRISM calls are for investigations utilizing suites of instruments (as opposed to individual payloads acquired under NPLP and LSITP) manifested on CLPS deliveries.

CLPS will deliver the PRISM-2 selections to the lunar south pole and the Gruithuisen Domes. The solicitation focuses on environmental monitoring at the south polar region, which will support Artemis crewed missions. The Gruithuisen Domes delivery is to a region of silicic late-stage volcanism and will help us understand the volcanic history of the Moon. This innovative approach for soliciting science investigations and technology demonstration payloads for future deliveries by CLPS providers will enable decadal caliber science at the Moon and support the Artemis campaign.

Recent Achievements

NASA released the PRISM-2 solicitation on September 2, 2021 and received 40 proposals. Down select proposals are due December 20, 2021, with final selections planned for spring 2022.

OTHER MISSIONS AND DATA ANALYSIS

Operating Missions

LUNAR RECONNAISSANCE ORBITER (LRO)

The LRO mission continues to conduct priority science investigations and acquire valuable data sets that provide critical support for commercial lunar deliveries under the CLPS project, as well as for human exploration. LRO has contributed to a new understanding of the Moon and its evolution, which provides a foundation for understanding all other objects in our solar system, as well as solar systems beyond our own. LRO's investigations include a focus on lunar volatiles like ice and water and answer questions like: what the volatiles are, where they come from, how they move about on the lunar surface, and where they collect. LRO has also been characterizing the thermal history of the Moon by identifying unusual volcanic features that may be geologically young, as well as tectonic features that reflect the continued gravitational pull from the Earth. Such features are targets for all seven instruments as the mission works to use multiple datasets to investigate the Moon. Scientists use the instrument suite on LRO to characterize the rate at which volatiles move across the surface, the development of the regolith on different terrains, and the location and composition of unusual rock types on the surface.

LRO will continue supporting characterization of the lunar surface, which ultimately enables and reduces risk associated with commercial and human exploration initiatives. Over the upcoming year, LRO will continue characterizing areas on the Moon that may contain volatiles at or near the surface and will characterize landing sites in support of the upcoming United States commercial lunar lander missions. LRO is also providing data products in support of current and future Artemis missions.

Recent Achievements

LRO, now in its 12th year of operation, has provided over 1.3 petabytes of lunar data to the planetary data system, which comprises over two-thirds of all planetary data ever acquired. LRO continued to acquire data to support upcoming CLPS missions and imaged the Chinese National Space Administration's Change'5 landing site prior to landing, during surface operations and after ascent into lunar orbit, which was a first in planetary science. LRO components are past their original design, but the LRO team continues to develop operational workarounds to accommodate the aging systems and the fuel is sufficient for approximately another five years of maneuvers.

DISCOVERY

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Psyche	175.6	138.7	**38.8**	29.0	32.0	32.0	35.4
DAVINCI	3.5	13.5	**22.8**	56.7	163.3	105.5	177.5
VERITAS	6.5	13.0	**57.2**	123.9	154.9	223.8	250.8
Other Missions and Data Analysis	262.1	171.5	**111.2**	160.1	190.3	233.3	222.6
Total Budget	**447.7**	**336.7**	**230.0**	**369.6**	**540.5**	**594.7**	**686.4**
Change from FY 2022 Budget Request			**-106.7**				
Percent change from FY 2022 Budget Request			**-31.7%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

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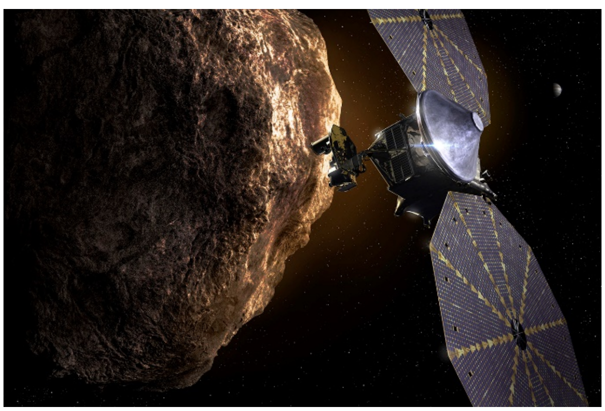


NASA's Lucy mission, depicted above, began its twelve-year odyssey through the solar system on October 16, 2021 to study Jupiter's Trojan asteroids, thought to be fossil records of early moments in our solar system's formation. Lucy is the first mission to journey to the outer solar system and back. Close fly-bys will allow for high resolution measurements of the full range of asteroid types. Two 24-foot wide solar panels supply the power to Lucy.

NASA's Discovery program supports competitively selected, investigator-led planetary science missions to explore the planets, their moons, and small bodies such as comets and asteroids. With a lower mission cost cap than most of NASA's other planetary missions, Discovery provides scientists the opportunity to propose innovative ways to unlock the mysteries of the solar system.

Missions in operation include Lucy and the Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport (InSight). Missions in formulation and development include Psyche, Janus, Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy (VERITAS), and Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (DAVINCI).

The Discovery program also supports the development of instruments that NASA contributes to foreign-led missions, such as the Start from a ROtating FIeld mass spectrOmeter (STROFIO) instrument on the BepiColombo mission. NASA has a partnership with the Japan Aerospace Exploration Agency (JAXA) for two contributions to its Martian Moons eXploration (MMX) mission, including the Mars-moon Exploration with Gamma rays and Neutrons (MEGANE) instrument and a

DISCOVERY

pneumatic sampler (P-Sampler). NASA is contributing the Venus Synthetic Aperture Radar (VenSAR) instrument to the European Space Agency's (ESA) EnVision mission.

The Discovery 2019 Announcement of Opportunity (AO) had a cost-cap of $500 million, excluding launch vehicle and mission operation costs. Launches have been separated by an average of ~43 months since the launch of the Gravity Recovery and Interior Laboratory mission in 2011 through the latest planned launch of DAVINCI in 2030. The Discovery Program also supports research based on completed Discovery missions, develops technology for potential missions to Venus and other planetary science priorities, and solicits SmallSat missions through the Small Innovative Missions for Planetary Exploration (SIMPLEx) effort.

EXPLANATION OF MAJOR CHANGES IN FY 2023

NASA selected two new Discovery missions from the Discovery 2019 AO, VERITAS and DAVINCI, and approved the contribution of the VenSAR instrument to the ESA EnVision mission to Venus.

NASA has delayed the release of the next Discovery AO (previously planned for 2023) due to budget challenges within the Discovery Program and the broader Planetary Science portfolio. Higher-than-expected costs for the development of Mars Sample Return and other large missions are placing significant pressure on other planetary programs. The Planetary Science and Astrobiology Decadal Survey, expected this spring, will provide additional guidance regarding the Discovery program.

This budget request updated the Lucy and Psyche mission profiles to reflect current KDP-E and prime operations planning and adds two new SIMPLEx missions in the outyears in the Planetary SmallSat project.

ACHIEVEMENTS IN FY 2021

In November 2020, NASA received the concept study reports for the four missions selected for Step 2 from the 2019 Discovery AO.

InSight completed its prime mission on December 31, 2020 and began its extended mission operations phase.

Psyche completed its Key Decision Point (KDP)-D review in January 2021 and began assembly, integration, and testing of flight hardware.

After thorough evaluation of the CSRs submitted to the Discovery 2019 AO, in June 2021, NASA down-selected the VERITAS and DAVINCI missions to proceed into formulation

In July 2021, NASA approved contributing the VenSAR instrument to ESA's EnVision mission, which is expected to launch in 2031.

Lucy completed its KDP-E review in September 2021 and received approval to implement science operations following launch.

DISCOVERY

WORK IN PROGRESS IN FY 2022

The Lucy mission successfully launched on October 16, 2021. Spacecraft and instrument commissioning will occur in FY 2022 in preparation for the first of three Earth gravity assists in early FY 2023. With Lucy in a cruise phase, ground-based observation campaigns will continue to study the properties of its targets to refine plans for encounter operations.

Psyche continues to make progress in the assembly, integration, and testing of flight hardware in preparation for the delivery of the completed spacecraft to the launch site in the spring of 2022.

Janus will complete its system integration and testing and deliver the spacecraft for launch. NASA plans to launch the Janus rideshare mission along with Psyche in August 2022.

InSight will continue attempts to clean its solar panels to prolong its operational life.

VERITAS, DAVINCI, and VenSAR will conduct risk reduction and science optimization activities.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

Lucy will perform its first Earth Gravity Assist. Psyche and Janus will conduct prime mission operations, and VERITAS, DAVINCI and VenSAR will continue in formulation.

Program Schedule

Date	Significant Event
Q4 FY 2022	Psyche and Janus Launch
Q1 FY 2023	Lucy Earth Gravity Assist
2025	Lucy first encounter with asteroid
TBD	Release Discovery AO based on Decadal Survey recommendation

Program Management & Planned Cadence

The Discovery Program is a multiple-project program, with responsibility for implementation assigned to the Planetary Missions Program Office, located at the Marshall Space Flight Center (MSFC).

The present launch cadence, calculated from 2011 through 2030, is ~43 months, with variations in the meantime between launches from nine to 80 months. With this budget request, missions selected under Discovery 2025 would launch in 2032 and 2034, which would represent a 24-month cadence with four launches over the period of 2028-2034.

DISCOVERY

Acquisition Strategy

NASA competitively selects new Discovery missions, releasing AOs when available funding allows.

INDEPENDENT REVIEWS

NASA will schedule the Discovery Program's next Program Implementation Review (PIR) when recommended by the primary stakeholders.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
PIR	Standing Review Board (SRB)	Aug 2016	Review implementation of program	Passed	TBD

PSYCHE

Formulation	Development	Operations

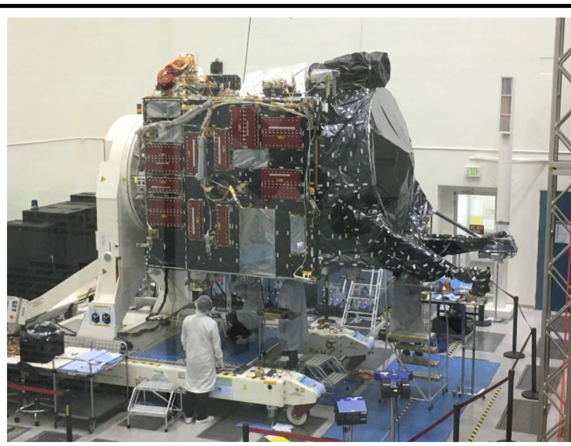
FY 2023 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027	BTC	Total
Formulation	143.7	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	143.7
Development/Implementation	336.8	175.6	138.7	**0.0**	0.0	0.0	0.0	0.0	0.0	651.1
Operations/Close-out	0.0	0.0	0.0	**38.8**	29.0	32.0	32.0	35.4	13.7	180.9
2022 MPAR LCC Estimate	**480.5**	**175.6**	**138.7**	**38.8**	**29.0**	**32.0**	**32.0**	**35.4**	**13.7**	**975.7**
Total Budget	**480.5**	**175.6**	**138.7**	**38.8**	**29.0**	**32.0**	**32.0**	**35.4**	**13.7**	**975.7**
Change from FY 2022 Budget Request				**-99.9**						
Percent change from FY 2022 Budget Request				**-72.0%**						

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The 2022 MPAR LCC Estimate reflects the Fiscal Year 2022 Quarter 1 Financial Report, which is current as of December 2021. The requested budget authority is the project's current budget requirements which have seen programmatic changes approved by NASA since December 2021.



Shown here is the assembled Psyche spacecraft in highbay at JPL. The spacecraft is being prepared for environmental testing which began in December 2021.

PROJECT PURPOSE

The Psyche mission will explore one of the most intriguing targets in the main asteroid belt: a giant metal asteroid known as 16 Psyche. This asteroid measures approximately 140 miles in diameter and, unlike most other asteroids that are rocky or icy bodies, is likely comprised mostly of metallic iron and nickel, similar to Earth’s core. Scientists theorize that Psyche may be the exposed core of an early planet that could have been as large as Mars but lost its rocky outer layers due to a number of violent collisions billions of years ago. The mission will help scientists understand how planets and other bodies separated into their layers, including cores, mantles, and crusts, early in their histories.

PSYCHE

Formulation	Development	Operations

NASA selected the Psyche mission in December 2016 from the Discovery Program's 2014 Announcement of Opportunity (AO).

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

PROJECT PARAMETERS

NASA plans to launch the mission in August 2022 for arrival at 16 Psyche in January 2026, where the spacecraft will spend 21 months in four different orbits. Each orbit will be successively closer to the asteroid to study its shape and magnetic field, topography and spectral characteristics, gravitational field, and elemental compositions. Each orbit provides knowledge needed to guide one or more future orbits, and operators have ample time to update the models, plans, and sequences.

Psyche's instrument payload includes a multispectral imager, a gamma ray and neutron spectrometer, and a magnetometer. Psyche will use an X-band radio telecommunications system to measure 16 Psyche's gravity field.

Psyche will also carry the flight terminal for the Deep Space Optical Communications (DSOC) technology demonstration, a project funded by the Space Technology Mission Directorate (STMD) and the Human Exploration and Operations Mission Directorate (HEOMD) to help mature the use of lasers to communicate with spacecraft, beyond low-Earth orbit (LEO).

ACHIEVEMENTS IN FY 2021

Psyche successfully held its System Integration Review in December 2020 and passed its Key Decision Point-D (KDP-D) review in January 2021. In March 2021, the project began assembly, integration, and testing (Phase D) of the flight hardware.

WORK IN PROGRESS IN FY 2022

Psyche will complete spacecraft assembly, integration, and test activities and deliver the spacecraft to the launch site in May 2022. The project will also complete its Operations Readiness Review (ORR) in May 2022 and the Key Decision Point-E (KDP-E) review in July 2022. The spacecraft will launch in August 2022.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

Psyche will continue the outbound cruise portion of the mission throughout FY 2023, executing a Mars Gravity Assist maneuver in May 2023.

PSYCHE

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2023 PB Request
KDP-C	Jun 2019	May 2019
CDR	Apr 2020	May 2020
System Integration Review (SIR)	Dec 2020	Dec 2020
KDP-D	Jan 2021	Jan 2021
Operations Readiness Review (ORR)	May 2022	May 2022
Launch	Aug 2022	Aug 2022
Phase E Start	Oct 2022	Oct 2022

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2020	681.9	70%	2022	651.1	-4.5%	Launch Readiness Date (LRD)	Aug 2022	Aug 2022	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

PSYCHE

Formulation	Development	Operations

Development Cost Details

The reduction in the Development cost estimate was mainly due to the selection of the SpaceX Falcon Heavy as the launch vehicle for the mission.

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**681.9**	**651.1**	**-30.8**
Aircraft/Spacecraft	199.9	286.4	+86.5
Payloads	49.6	79.7	+30.1
Systems I&T	19.2	22.5	+3.3
Launch Vehicle	154.3	112.7	-41.6
Ground Systems	16.1	21.0	+4.9
Science/Technology	9.3	8.8	-0.5
Other Direct Project Costs	233.5	119.9	-113.5

Project Management & Commitments

The Principal Investigator is from Arizona State University (ASU) and leads the management of the mission. The Jet Propulsion Laboratory (JPL) serves as the development center for the Psyche mission and provides systems engineering, mission assurance, spacecraft design, build, test, mission and science operations, navigation, and ground data systems.

Element	Description	Provider Details	Change from Baseline
Solar Electric Propulsion Chassis	Spacecraft bus and propulsion system	Provider: Maxar Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Psyche Multispectral Imager	Provides high-resolution images using filters to discriminate between 16 Psyche's metallic and silicate constituents	Provider: ASU Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

PSYCHE

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Magnetometer	Detects and measures the remnant magnetic field of 16 Psyche	Provider: University of California, Los Angeles (UCLA) Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	Removed from the mission
Magnetometer	Detects and measures the remnant magnetic field of 16 Psyche	Provider: Technical University of Denmark (DTU) Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	Replacement magnetometer
Gamma Ray and Neutron Spectrometer	Detects, measures, and maps 16 Psyche's elemental composition	Provider: APL Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Gravity Science	Utilizes the X-band radio telecommunications system to measure 16 Psyche's gravity field	Provider: Massachusetts Institute of Technology (MIT) Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Launch Vehicle	Launch vehicle and launch services	Provider: Space Exploration Technologies Corp. (SpaceX) Lead Center: Kennedy Space Center (KSC) Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Deep Space Optical Communications (DSOC)	DSOC will mature the use of lasers to communicate with spacecraft beyond low-Earth orbit	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): NASA SOMD/STMD	N/A

PSYCHE

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: Additional delays are encountered in the delivery of flight model instruments and spacecraft components (e.g., the Imager instrument and Reaction Wheel Assemblies [RWA]), Then: The Assembly, Test, and Launch Operations (ATLO) schedule will be put at risk and the project could incur additional costs.	Project and program management are closely monitoring the final delivery of flight Imager and RWA components, adjusting the ATLO schedule to accommodate delays, and identifying alternatives to meet the launch readiness date (LRD).

Acquisition Strategy

NASA selected the Psyche mission through a competitive Discovery 2014 AO and a down-selection in FY 2017. All major acquisitions are in place. The major elements of the mission and spacecraft are as proposed in the AO. NASA competitively selected the launch vehicle through the NASA Launch Services program.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Spacecraft	Maxar	Palo Alto, CA
PI, Co-Is, Imager, Science Data Center	Arizona State University	Tempe, AZ
Launch Vehicle	SpaceX	Hawthorne, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	Mar 2019	PDR	Successful	CDR
Performance	SRB	May 2020	CDR	Successful	SIR

PSYCHE

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Dec 2020	SIR	Successful	ORR
Performance	SRB	May 2022	ORR	TBD	N/A

DEEP ATMOSPHERIC VENUS INVESTIGATION OF NOBLE GASES, CHEMISTRY & IMAGING

Formulation	Development	Operations

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**3.5**	**13.5**	**22.8**	**56.7**	**163.3**	**105.5**	**177.5**
Change from FY 2022 Budget Request			**9.3**				
Percent change from FY 2022 Budget Request			**68.9%**				

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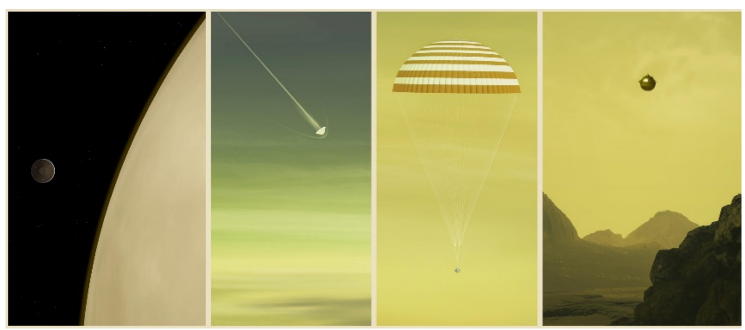
PROJECT PURPOSE



Depicted above is the DAVINCI mission's flyby, probe release, parachute descent, and final freefall. Instruments in the descent sphere will provide unprecedented detail of atmospheric composition along with surface images that will enable a new view of Venus and help determine whether Venus had an ocean.

The DAVINCI mission will provide a definitive, new understanding of Venus to help reveal the extent of potential habitability in our inner solar system. The DAVINCI mission addresses three overall goals:

- Understand the origin and evolution of the Venus atmosphere;
- Understand the atmospheric composition and its interaction with the surface; and
- Provide insights into the properties of the tesserae surface features which are highly deformed, high elevation features.

The first goal is important to comparative planetology questions within our solar system by answering how and why Venus, Mars and Earth are different; and by answering questions on how Venus compares to Earth-sized exoplanets. The second goal will help address questions about the interactions of Venus's atmosphere and surface features, such as the presence of an early ocean or the rate of volcanic activity. Four instruments in the Descent Sphere "probe" will address the mission's first two goals, as they will make measurements of the current composition of Venus's atmosphere while the probe moves through the atmosphere to the surface of the planet. The third goal will help address questions about tesserae features such as how they formed and how they compare with other features on Venus. Two imagers, one on the probe itself and another on the main spacecraft will help answer these questions.

DEEP ATMOSPHERIC VENUS INVESTIGATION OF NOBLE GASES, CHEMISTRY & IMAGING

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2023

DAVINCI is a new mission in formulation. NASA selected DAVINCI in June 2021 from the 2019 Discovery AO.

PROJECT PRELIMINARY PARAMETERS

The mission consists of a spacecraft and a probe. The spacecraft will track motions of the clouds and map surface composition by measuring heat emission from Venus' surface that escapes to space through the massive atmosphere. The probe will descend through the atmosphere, sampling its chemistry as well as the temperature, pressure, and winds. The probe will also take the first high-resolution images of Alpha Regio, an ancient highland twice the size of Texas with rugged mountains, looking for evidence that past crustal water influenced surface materials.

Launch is targeted for FY 2030 with two flybys of Venus prior to the probe's descent. The flybys are the initial phase of the remote-sensing mission to study the atmospheric circulation and map the surface composition. Approximately two years later, the spacecraft will release the probe to conduct its investigation of the atmosphere during a descent that will last about an hour before landing at Alpha Regio. The planned mission data return is ~ 65 gigabits, with up to 500 descent images, hundreds of trace gas spectra, millions of UV spectra, and thousands of near-infrared nightside images. The total mission duration is two years and one month.

NASA also selected the Compact Ultraviolet to Visible Imaging Spectrometer (CUVIS) Technology Demonstration Opportunity (TDO) as part of DAVINCI. It will demonstrate the technology readiness of freeform optics for collecting high-resolution measurements of spectra and artificial intelligence for onboard data processing. Scientists will use the observations collected by CUVIS to identify the unknown UV-absorber in the atmosphere of Venus, which absorbs half of the incoming solar energy.

ACHIEVEMENTS IN FY 2021

NASA selected DAVINCI to enter formulation in June 2021. The project began formulating detailed cost and schedule plans.

WORK IN PROGRESS IN FY 2022

The project team continues to mature cost and schedule plans to align with the NASA launch schedule and budget. The team has begun system requirements derivation, development of the Interface Control Document and Concept of Operations, and mission design optimization.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

The project team will conduct a preliminary system requirement review in FY 2023.

DEEP ATMOSPHERIC VENUS INVESTIGATION OF NOBLE GASES, CHEMISTRY & IMAGING

Formulation	Development	Operations

ESTIMATED PROJECT SCHEDULE

The DAVINCI schedule is currently under evaluation. The dates shown below are preliminary and subject to change.

Milestone	Formulation Authorization Document	FY 2023 PB Request
Formulation Authorization	N/A	Jun 2021
PDR	N/A	Sep 2025
KDP-C	N/A	Nov 2025
CDR	N/A	Mar 2027
SIR	N/A	Feb 2028
KDP-D	N/A	Mar 2028
KDP-E	N/A	TBD
Launch	N/A	FY 2030

Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

Life cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows a non-advocate review and/or preliminary design review.

KDP-B Date	Estimated Life Cycle Cost Range ($B)	Key Milestone	Key Milestone Estimated Date Range
Jun 2021	$1.2B - $1.6B	LRD	Jun 2029 - Nov 2029

Project Management & Commitments

The Principal Investigator for DAVINCI is from Goddard Space Flight Center (GSFC) and GSFC also manages the mission and will provide systems engineering, safety and mission assurance, project scientists, flight dynamics, payload management, and mission system management.

DEEP ATMOSPHERIC VENUS INVESTIGATION OF NOBLE GASES, CHEMISTRY & IMAGING

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
DAVINCI Spacecraft	Spacecraft delivers the descent sphere and hosts two instruments. Spacecraft's most important role is to deliver the descent sphere and then relay its data back to Earth.	Provider: Lockheed Martin Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Descent Sphere	One-meter diameter probe that falls through Venus' atmosphere making continuous measurements to the planet's surface.	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Venus Atmospheric Structure Investigation (VASI) Instrument	Descent sphere instrument to characterize the structure and dynamics of Venus atmosphere (every ~15m from 67 km to surface)	Provider: Johns Hopkins University/Applied Physics Laboratory (JHU/APL) Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Venus Mass Spectrometer (VMS)	Descent sphere instrument to survey the planet's noble gases and their isotopes, as well as trace gases	Provider: GSFC Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Venus Descent Imager (VenDI)	Descent sphere instrument (broadband and narrowband NIR) to image Venus from ~38 km down to the surface to define topography and composition	Provider: Malin Space Science Systems Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Venus Tunable Laser Spectrometer (VTLS)	Descent sphere instrument to discriminate chemical processes in upper clouds and near surface environment (10 ingests), including the deuterium/hydrogen ratio	Provider: Jet Propulsion Laboratory (JPL) Lead Center: GSFC Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Venus Imaging System for Observational Reconnaissance (VISOR)	Spacecraft instrument to image full disk upper atmosphere in UV (movies) and 1 µm nightside emissivity (highlands)	Provider: Malin Space Science Systems Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

DEEP ATMOSPHERIC VENUS INVESTIGATION OF NOBLE GASES, CHEMISTRY & IMAGING

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
Venus Oxygen Fugacity (VfOx)	Descent sphere instrument (solid-state sensor) to measure O2 partial pressure in lower atmosphere, student collaboration	Provider: JHU/APL Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
CUVIS	Spacecraft technology demonstration instrument (UV spectrometer) to determine chemistry of upper clouds and mystery absorber	Provider: GSFC Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Launch Vehicle	Launch vehicle and all launch services	Provider: TBD Lead Center: KSC Performing Center(s): KSC Cost Share Partner(s): N/A	N/A

Project Risks

The DAVINCI Project team has not established baseline project risks at this point.

Acquisition Strategy

NASA competitively selected the DAVINCI mission through a Discovery 2019 Announcement of Opportunity (AO). The major elements of the mission and spacecraft are as proposed for the AO, including the prime contract with Lockheed Martin. NASA will competitively select the launch vehicle through the NASA Launch Services Program.

DEEP ATMOSPHERIC VENUS INVESTIGATION OF NOBLE GASES, CHEMISTRY & IMAGING

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Spacecraft	Lockheed Martin	Denver, CO
Navigation analysis	KinetX	Tempe, AZ
VMS instrument electronics	University of Michigan	Ann Arbor, MI
Venus Test Chamber development	National Technical Systems, Inc	Huntsville, AL
VASI instrument development	JHU/APL	Laurel, MD

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Sep 2025	PDR	TBD	CDR
Performance	SRB	Mar 2027	CDR	TBD	SIR
Performance	SRB	Feb 2028	SIR	TBD	ORR
Performance	SRB	TBD	ORR	TBD	N/A

VENUS EMISSIVITY, RADIO SCIENCE, INSAR, TOPOGRAPHY AND SPECTROSCOPY

Formulation	Development	Operations

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**6.5**	**13.0**	**57.2**	**123.9**	**154.9**	**223.8**	**250.8**
Change from FY 2022 Budget Request			**44.2**				
Percent change from FY 2022 Budget Request			**340.0%**				

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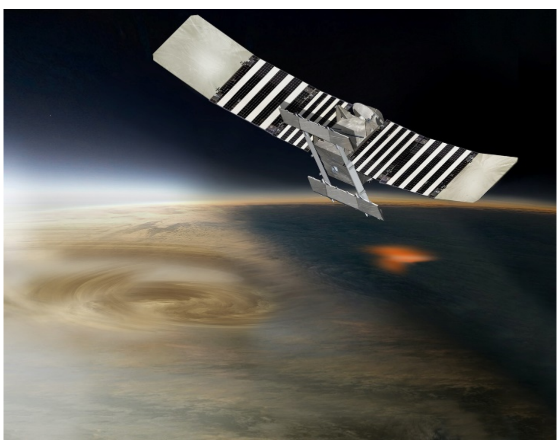


Shown here is an artist's impression of the VERITAS spacecraft design.

PROJECT PURPOSE

The Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy (VERITAS) mission will map Venus' surface to determine the planet's geologic history and understand why it developed so differently than Earth. Orbiting Venus with a synthetic aperture radar, VERITAS will chart surface elevations over nearly the entire planet to create 3D reconstructions of topography and confirm whether processes such as plate tectonics and volcanism are still active on Venus.

VERITAS will also map infrared emissions from Venus' surface to map its rock type, which is largely unknown, and determine whether active volcanoes are releasing water vapor into the atmosphere.

Understanding planetary habitability requires identifying the factors that govern the surface environment over time. Venus very likely had characteristics essential to life, such as surface oceans and a protective magnetic field. And it may still have tectonism and volcanism, which are key to sustaining the atmospheric and surface chemical disequilibria needed to fuel life. What caused Venus, which has so many similarities to Earth, to diverge down such a different evolutionary path? To answer this question, the VERITAS mission will create high resolution data sets of topography, imagery, spectroscopy, and gravity. The combined observations will provide a new view of Venus as a control case for planetary evolution relevant not only to understanding how the Earth developed and maintained conditions suited for life, but also constraining habitability studies of exoplanets.

VENUS EMISSIVITY, RADIO SCIENCE, INSAR, TOPOGRAPHY AND SPECTROSCOPY

Formulation	Development	Operations

NASA selected VERITAS as a Discovery mission in June 2021 from the 2019 Discovery Announcement of Opportunity (AO).

EXPLANATION OF MAJOR CHANGES IN FY 2023

VERITAS is a new mission in formulation.

PROJECT PRELIMINARY PARAMETERS

VERITAS will launch in FY 2028 and conduct a three-year science mission operating from a polar orbit around Venus. The Venus Interferometric Synthetic Aperture Radar (VISAR) on VERITAS will deliver a long-awaited digital elevation model at 250-meter horizontal postings by six-meter height accuracy, image the planet at 30 meters and 15 meters resolution, and provide the first interferometric deformation maps of activity on another planet. The Venus Emissivity Mapper (VEM) will deliver near-global, high-SNR maps of Venus emissivity using six surface spectral bands to provide detailed information on surface rock type and current and recent volcanism. The mission also includes a gravity science investigation using the spacecraft telecommunication system that will provide the first estimate of core size and state, as well as crustal elastic thickness and heat flow.

ACHIEVEMENTS IN FY 2021

NASA selected VERITAS in June 2021 to enter formulation.

WORK IN PROGRESS IN FY 2022

VERITAS is currently completing an updated cost and schedule plan establishing new milestones and LRD based on projected budget availability. Work in FY 2022 will focus on risk reduction activities, in particular for the VISAR instrument and telecommunications hardware (contributed by the Italian Space Agency - ASI), among other technologies.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

VERITAS will focus on risk reduction activities and preparing for the Project Mission System Review (PMSR) in early FY 2024.

ESTIMATED PROJECT SCHEDULE

The VERITAS schedule is currently under evaluation. The dates shown below are preliminary and subject to change.

VENUS EMISSIVITY, RADIO SCIENCE, INSAR, TOPOGRAPHY AND SPECTROSCOPY

Formulation	Development	Operations

Milestone	Formulation Authorization Document	FY 2023 PB Request
PMSR	N/A	Oct 2023
PDR	N/A	Aug 2024
KDP-C	N/A	Dec 2024
CDR	N/A	Aug 2025
System Integration Review (SIR)	N/A	May 2026
KDP-D	N/A	Jul 2026
Operations Readiness Review (ORR)	N/A	Aug 2027
Launch	N/A	Nov 2027

Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

Life cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows a non-advocate review and/or preliminary design review.

KDP-B Date	Estimated Life Cycle Cost Range ($B)	Key Milestone	Key Milestone Estimated Date Range
Jun 2021	$1.2 - $1.6 B	LRD	2027 - 2028

Project Management & Commitments

The Principal Investigator is from the Jet Propulsion Laboratory (JPL) and JPL also serves as the implementing center for the VERITAS mission. JPL provides systems engineering, mission assurance, payload management, mission and science operations, navigation, and ground data systems.

VENUS EMISSIVITY, RADIO SCIENCE, INSAR, TOPOGRAPHY AND SPECTROSCOPY

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
Spacecraft	Venus orbiter that carries the science (VISAR, VEM) payloads during cruise and will conduct the Venus Orbit Insertion (VOI), aerobraking and science operations.	Provider(s): Lockheed Martin Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Venus Emissivity Mapper	Provides near-global maps of mafic to felsic rock type and will search for active and recent volcanism.	Provider: DLR - German Aerospace Center Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): DLR	N/A
Venus Interferometric Synthetic Aperture Radar	Designed to acquire high resolution imagery and topography of Venus as well as to make repeat pass interferometric measurements of surface deformation	Provider(s): JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): DLR and the Italian Space Agency	N/A
Gravity Science	Enables estimation of elastic thickness (a proxy for thermal gradient) and density differences due to subsurface structures, as well as constraining interior structure, including core size and state	Provider(s): GSFC, Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): ASI - University of Roma	N/A
Launch Vehicle	Launch vehicle and launch services	Provider: TBD Lead Center: Kennedy Space Center (KSC) Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Integrated Deep Space Transponder and High Gain Antenna	Receives commands and transmits data/telemetry to Earth via the High Gain Antenna (HGA)	Provider: ASI - Italian Space Agency Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): ASI - Italian Space Agency	N/A

VENUS EMISSIVITY, RADIO SCIENCE, INSAR, TOPOGRAPHY AND SPECTROSCOPY

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
Ka-band Traveling Wave Tube Amplifier	Amplifies the Ka-band downlink signal prior to transmission to Earth via the HGA.	Provider: CNES - French Space Agency Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): CNES - French Space Agency	N/A

Project Risks

Risk Statement	Mitigation
If: The VISAR Digital Electronics Subsystem is delivered late, Then: VERITAS will incur additional costs to accommodate late delivery to and integration with the spacecraft.	The project assigned additional resources and management/engineering support to mitigate schedule risk.

Acquisition Strategy

NASA competitively selected the VERITAS mission through a Discovery 2019 AO and a down-select in 2021. The major elements of the mission and spacecraft are as proposed for the AO. NASA will competitively select the launch vehicle through the NASA Launch Services Program.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Spacecraft, System Integration and Test, Launch Operations, Mission Operations	Lockheed Martin	Denver, CO

VENUS EMISSIVITY, RADIO SCIENCE, INSAR, TOPOGRAPHY AND SPECTROSCOPY

Formulation	Development	Operations

INDEPENDENT REVIEWS

All dates shown below are preliminary.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	NASA Standing Review Board (SRB)	Aug 2024	PDR	TBD	Aug 2025
Performance	SRB	Aug 2025	CDR	TBD	May 2026
Performance	SRB	May 2026	SIR	TBD	Aug 2027
Performance	SRB	Aug 2027	ORR	TBD	TBD

OTHER MISSIONS AND DATA ANALYSIS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
EnVision	3.4	7.2	**16.1**	38.9	45.2	47.4	42.9
Janus	23.7	15.3	**1.2**	0.6	0.6	1.1	0.0
Venus Technology	4.9	6.6	**7.0**	7.3	7.5	7.0	7.0
InSight	14.9	14.6	**7.8**	14.8	3.7	0.0	0.0
Lucy	139.9	43.3	**22.9**	24.8	26.4	23.3	38.1
Strofio	1.3	1.0	**0.9**	1.0	1.8	1.2	2.3
International Mission Contributions (IMC)	5.5	10.3	**7.8**	7.5	8.9	9.7	8.0
Planetary Management	22.2	18.9	**20.4**	20.9	32.6	27.5	23.5
Discovery Future	22.4	22.2	**13.7**	11.4	12.2	54.1	62.6
Discovery Research	6.8	9.7	**9.7**	10.2	11.5	12.8	13.8
Planetary SmallSats	4.8	14.7	**0.9**	20.3	37.1	46.1	22.6
Mars-moon Exploration with GAmma Rays an	12.2	7.9	**2.8**	2.6	2.8	3.2	2.0
Total Budget	**262.1**	**171.5**	**111.2**	**160.1**	**190.3**	**233.3**	**222.6**
Change from FY 2022 Budget Request			**-60.3**				
Percent change from FY 2022 Budget Request			**-35.2%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Shown here is the launch of the Lucy Mission, a 12-year mission to characterize the Trojan Asteroids, which launched on October 16, 2021.

Discovery Other Missions and Data Analysis funds research and analysis; management activities; operations of active missions; small projects and international collaborations; and funding for future mission selections.

Mission Planning and Other Projects

JANUS

Janus is a planned dual spacecraft rideshare mission that will visit two binary asteroids, (175706) 1996 FG3 and (35107) 1991 VH, to study the formation of small "rubble pile" asteroids. The mission will launch as a secondary payload with the Psyche

OTHER MISSIONS AND DATA ANALYSIS

spacecraft in August 2022 and arrive at the two binary asteroids in 2026. Janus will perform a flyby to collect data in infrared and visible light. It will be the world's first flyby and close-up observation of a binary asteroid pair.

Recent Achievements

The Janus mission entered its final design and fabrication phase in 2021, requiring a change to the propulsion system. Using newly developed thrusters, the thrusters continue environmental testing into FY 2022.

VENUS TECHNOLOGY

The surface of Venus is an extreme environment with high temperatures and pressures (500 degrees Celsius and 90 bars) and an acidic atmosphere that presents unique challenges to robotic missions. The Venus Technology project focuses on developing and advancing technologies that future missions will use to explore Venus and other worlds. Venus Technology includes: the Hot Operating Temperature Technology (HOTTech) element, which supports development of technologies for high-temperature environments such as Venus, Mercury, and the deep atmospheres of the gas giant planets; the Glenn Extreme Environment Rig (GEER), which is a pressure vessel capable of simulating the temperature, pressure and atmospheric gas mix of Venus and other extreme environments in the solar system and beyond; and the Long-Lived In-Situ Solar System Explorer (LLISSE), which is an exploration module designed to support scientific observations in the extreme environment of Venus.

Recent Achievements

LLISSE's 16-cell battery successfully operated under simulated loads for over 125 days at 500 degrees Celsius, demonstrating a design that can meet the lifetime requirements for a long-duration surface mission.

NASA received 38 proposals in response to the second HOTTech solicitation, which focused on developing electrical and electronic systems or components to enable or enhance in-situ robotic missions requiring long duration operation (at least 60 days) on the hot surface of Venus. These operations include exposing the spacecraft and its components to the caustic Venus atmosphere. NASA made seven selections in November 2021, encompassing core technologies needed for power, communications, electronics, and sensing.

GEER was inactive most of 2021 because of an extended COVID-19 lab shutdown at the Glenn Research Center. The GEER team worked with the Juno mission and with investigators funded by LLISSE, Solar Systems Workings (SSW), and HOTTech to support planning for future tests. The team also supported proposers to HOTTech and SSW solicitations.

INTERNATIONAL MISSION CONTRIBUTIONS (IMC)

There are more scientifically interesting destinations across the solar system than any one country's program can undertake. NASA works closely with other space agencies to find opportunities to participate in each other's missions. These opportunities complement NASA-led planetary missions and expand the opportunities for NASA and the United States planetary science community to address scientific priorities identified in the Decadal Survey. Under the International Mission Contributions,

OTHER MISSIONS AND DATA ANALYSIS

NASA funds instruments and scientific investigators and provides navigation and data relay services in exchange for participation in mission science. International missions currently supported include: the JAXA’s Hayabusa2, Akatsuki (Venus Climate Orbiter), and MMX missions, the Korea Pathfinder Lunar Orbiter (KPLO), and ESA's newly announced EnVision mission.

The Pneumatic Sampler (P-Sampler) is also an element in IMC and is a technology demonstration instrument in development by Honeybee Robotics as a second NASA contribution to JAXA's MMX mission. The P-Sampler will complement the JAXA-developed primary surface sampler system by demonstrating the collection of surface and near-surface material on the Martian moon Phobos by using compressed gas jets.

Recent Achievements

The Hayabusa2 capsule with its payload of samples from the Ryugu asteroid landed in Australia in December 2020. Despite the challenges posed from COVID-19, NASA deployed two aircraft to observe capsule-heating during atmospheric entry. Teams can now use these observations to plan for future landing systems on Earth and other worlds. Preliminary work on the Hayabusa2 reentry indicates that NASA may be able to use thinner and lighter heat shields for future missions. Analysis of Hayabusa2 samples will begin in 2022.

In the summer of 2021, NASA selected Participating Scientists to support the KPLO mission. These scientists will help with mission and science planning in preparation for launch, currently scheduled for late FY 2022.

NASA continues to study a Venus flagship mission concept (Venera-D) with the Russian Space Research Institute (IKI)/Roscosmos.

P-Sampler conducted its Critical Design Review in October 2021 and continues in Phase C development.

ENVISION

ESA announced the selection of the EnVision mission to Venus in June 2021. EnVision is ESA’s next Venus orbiter, providing a holistic view of the planet from its inner core to upper atmosphere to determine how and why Venus and Earth evolved so differently. EnVision will launch in 2032. NASA has committed to contributing the Venus Synthetic Aperture Radar (VenSAR) to the mission. VenSAR will provide imaging and ranging techniques from a polar orbit for regional and targeted surface imaging, topography from altimetry stereo imaging, surface properties from polarimetry and radiometry and change detection from repeat imaging and comparison to Magellan.

Recent Achievements

VenSAR entered Phase A and is conducting early formulation studies.

PLANETARY MANAGEMENT

The Planetary Missions Program Office (PMPO) at Marshall Space Flight Center manages nearly all Planetary Science flight projects that are not part of the Mars Exploration Program, including the competed Discovery and New Frontiers missions, the directed Solar System Exploration Program and

OTHER MISSIONS AND DATA ANALYSIS

Planetary Defense Coordination Office flight missions. The PMPO includes support for the day-to-day efforts of the mission managers and business office, as well as independent review boards and external technical support as needed for the projects. This project also funds the Science Office for Mission Assessments at Langley Research Center to support the competed mission selection process, including the development of Announcements of Opportunity (AO) and the formation and operations of independent review panels to evaluate mission proposals.

DISCOVERY FUTURE

Discovery Future funds specific promising technology investments to enable future missions, mission concept development during step one of the AO down-select process, and small missions of opportunity.

Recent Achievements

In June 2021, NASA selected two missions from the 2019 Discovery AO to enter formulation: VERITAS and DAVINCI. NASA anticipates that the Planetary Science and Astrobiology Decadal Survey expected this spring will provide additional guidance regarding release of the next Discovery AO.

DISCOVERY RESEARCH

Discovery Research funds analysis of archived data from Discovery missions and supports participating scientists. Discovery Research gives the broad research community an opportunity for access to samples and data and allows research to continue for many years after mission completion. NASA solicits planetary research proposals from the United States planetary science community and evaluates them for selection through competitive peer review. Discovery Research also funds the analysis of samples returned to the Earth by the Stardust and Genesis missions, as well as the development of new analysis techniques for samples returned by future missions.

The Discovery Data Analysis Program element (DDAP) has provided support for continued analysis of spacecraft data from the Near Earth Asteroid Rendezvous (NEAR)-Shoemaker, Stardust, Stardust-New Exploration of Tempel, Genesis, Deep Impact, Extrasolar Planet Observation and Characterization (EPOCh) and Deep Impact eXtended Investigation (DIXI), Mercury Surface, Space Environment, Geochemistry and Ranging (MESSENGER), Dawn, and Kepler missions. The supported projects conduct new scientific inquiries and regularly obtain new and unexpected scientific results, using data sets to go beyond the work conducted by the original mission teams. The Rosetta Data Analysis Program element (RDAP) has provided additional support targeted for analysis of data from Rosetta, an ESA-led mission with NASA participation, to explore and land on Comet 67P/Churyumov-Gerasimenko.

Recent Achievements

The program awarded 12 new research projects in 2021. These included data from three different Discovery missions; MESSENGER data from Mercury, DAWN data from Ceres, and NEAR data from asteroid 433 Eros. Work on Comet 67P/ Churyumov-Gerasimenko supports one Rosetta-based study. Despite a slowdown in research productivity due to COVID-19, scientists announced exciting new results for Mercury. First, it appears that the MESSENGER spacecraft witnessed a large meteoroid impact on Mercury, which is the first ever observation of an impact on the surface of another rocky planet as prior impacts were only observed on the Earth and the Moon. Using MESSENGER's Fast-Imaging Plasma

OTHER MISSIONS AND DATA ANALYSIS

Spectrometer (FIPS), researchers detected an unusually large number of sodium and silicon ions blowing in the Sun's solar wind in a tight beam. Using the particles' speed and direction, they tracked them back to their source, a plume from Mercury's surface that extended nearly 3,300 miles into space. The impact from a three-foot wide meteor likely caused the plume. Understanding meteoroid impacts is critical to understanding the source processes of the exosphere at Mercury, and the use of plasma spectrometers will be crucial for future observations with the Bepi Colombo mission on which NASA partners with ESA.

The second Mercury result provided new constraints on the processes of sodium loss from Mercury's exosphere. Sodium is a scientifically important species because it is both easily observed and functions as an important tracer of microphysical processes which are known to vary seasonally with the planet's distance from the Sun. In short, the amount of neutral sodium lost due to acceleration by radiation sets the amount of sodium lost through photoionization, but scientists had not quantified the relative importance of these processes. Researchers determined Mercury's photoionization rate through measurements from MESSENGER's FIPS and UltraViolet and Visible Spectrometer instruments combined with observations from the ground-based THEMIS solar telescope. The results show that photoionization on Mercury drives sodium loss at rates like those observed for Venus and Mars. These losses are seasonally dependent, but overall are equal to or greater than the losses induced by acceleration. Consequently, photoionization is a critical control on Mercury's exosphere.

PLANETARY SMALLSATS

NASA established the Small Innovative Missions for Planetary Exploration (SIMPLEx) program element to develop and operate targeted science investigations that exploit the unique attributes of small spacecraft to conduct compelling science. These small satellite missions take advantage of available launch capacity on larger missions to reduce the overall costs of launching multiple missions, provide a means to mature technologies for future missions, and serve as additional opportunities to provide flight experience to the workforce.

In June 2019, NASA announced the selection of three small satellite missions under the SIMPLEx Program: Janus, Escape and Plasma Acceleration and Dynamics Explorers (EscaPADE), and Lunar Trailblazer. Janus is now its own project in Discovery. Heliophysics manages EscaPADE and Lunar Trailblazer is funded in the Lunar Development and Exploration Program.

MEGANE

The Mars-moon Exploration with Gamma rays and Neutrons (MEGANE, also Japanese for "eyeglasses") instrument is a gamma-ray and neutron spectrometer currently in development by the Johns Hopkins University Applied Physics Laboratory, as a contribution to the JAXA Martian Moons eXploration (MMX) mission. Planned for launch in 2024, MMX will operate near the Martian moons Phobos and Deimos for approximately three years and return a sample from Phobos to Earth in 2029. MEGANE will measure the bulk composition of the near-surface materials on Phobos to constrain theories for the origin of the moons. It will also map the near-surface materials on Phobos to enable the study of surface processes and support MMX sample site selection.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

MEGANE conducted its Critical Design Review in June 2021 and continues in its final design and fabrication phase (Phase C)

Operating Missions

LUCY

NASA's Lucy mission launched in October 2021 to explore a diverse population of small bodies known as the Jupiter Trojan asteroids. The Trojans are remnants of our early solar system, now trapped on stable orbits associated with Jupiter. The two "swarms" lead and follow Jupiter in its orbit around the Sun and are almost as numerous as the objects in the Main Asteroid Belt. Over its 12 year primary mission, Lucy will explore a record breaking number of asteroids, flying by one main belt asteroid and seven Trojan asteroids on a tour that sets another first by being the first mission to traverse from the inner to outer solar system and back again as it moves from the leading to trailing swarm.

Solar system formation models suggest that the Trojans are remnants of the same primordial material that formed the outer planets, and thus serve as time capsules from the birth of our solar system over four billion years ago. These primitive bodies hold vital clues to deciphering the history of our solar system and may even tell us about the kinds of organic materials supplied to the early Earth. The Lucy mission is in fact named after the Lucy fossil skeleton of a pre-human ancestor discovered in Ethiopia in 1974. Just as the Lucy fossil provided unique insights into humanity's evolution, the Lucy mission promises to revolutionize our knowledge of planetary origins.

Lucy's objectives are to determine the properties and history of the Trojan asteroids by mapping their surface geology, measuring their color and composition, and determining their mass and density, as well as searching for satellites and/or rings that might exist.

Recent Achievements

Lucy successfully launched on October 16th, 2021. Spacecraft and instrument commissioning are in progress. One of Lucy's two solar arrays failed to lock into the final, secure position. This unexpected state of the solar array could impact the mission by reducing available solar power or could cause damage if the unlocked array moves during navigation maneuvers. The team is studying potential options to resolve the issue.

INSIGHT

InSight is a robotic lander studying the deep interior and other aspects of Mars by measuring its seismic activity and making other measurements from the planet's surface. Launched on May 5, 2018, InSight landed on the surface of Mars at Elysium Planitia on November 26, 2018. The mission contributes to understanding the formation of rocky planets, including Earth, by investigating the crust and core of Mars, especially seismic activity generated by tectonic activity. One of the science payload's main instruments, the Seismic Experiment for Interior Structure (SEIS), is making precise measurements of quakes and other activity relevant to determining the planet's internal structure.

OTHER MISSIONS AND DATA ANALYSIS

A second instrument, the Heat Flow and Physical Properties Package (HP3), also known as the 'Mole', is a heat probe developed and built by the German Aerospace Center (DLR) and designed to burrow into the Martian surface to take the planet's internal temperature, providing details about the interior heat engine that drives the Mars' evolution and geology. InSight deployed the probe onto the Mars surface in February of 2019. Unfortunately, this probe was unable to burrow deeply enough into the Martian regolith to meet the heat flow measurement objective, penetrating only 40 cm. The team had to abandon their efforts. It is widely believed that the soil's unexpected tendency to clump deprived the spike-like mole of the friction it needed to hammer itself to a sufficient depth. The instrument continues to provide measurements of the ground temperature, thermal inertia, and thermal conductivity of the upper half-meter of the Martian soil. InSight also hosts the Rotation and Interior Structure Experiment (RISE) instrument which uses InSight's communications system to provide precise measurements of planetary rotation; the wobble provides insight into the size and composition of Mars' core. Finally, InSight also has wind, temperature, air pressure, and magnetic sensors.

Recent Achievements

InSight's prime mission consisted of two years of investigations of the deep interior of Mars that concluded at the end of 2020. During that time, InSight confirmed predictions that Martian seismic activity would be ~1,000 times lower than that of Earth. The team's preliminary estimates of seismic activity for marsquakes smaller than a magnitude 4.0 were generally accurate, but they detected fewer large marsquakes than expected. Of the more than 450 marsquakes detected by the SEIS instrument during the prime mission, approximately 40 were large enough to be useful in studying Mars' interior. Scientists determined the epicenters of three marsquakes, and all are near Cerberus Fossae, consistent with the region being known from orbital imaging to have geologically recent (a few million years or less) volcanic and tectonic activity. InSight observations of Mars' magnetic field at its surface--one of many firsts for this mission-- found that the local field is approximately 10 times larger than seen from orbit, which has important implications for determining the evolution of Mars' interior and atmosphere. InSight's pressure and wind sensors have been used to study Mars' weather with unprecedented resolution. These sensors have detected thousands of atmospheric vortices which were used to put limits on subsurface ground structure, including determining the stiffness of Martian soil.

NASA approved InSight for a two-year extended mission in December of 2020.

InSight is different from previous Mars missions in that its science relies on cumulative observations and advances with time. Approximately nine months since the beginning of the extended mission, Insight researchers detected more than 500 additional marsquakes, including three more quakes near Cerberus Fossae and four of the largest marsquakes seen during the entire mission. RISE uses the tracking data to provide additional constraints on the radius and density of the core. InSight has also continued to provide weather and magnetic measurements during its second year on Mars, allowing detailed studies of Martian weather and its year-to-year variability.

STROFIO

STROFIO (Start from a ROtating FIeld mass spectrOmeter) is a unique mass spectrometer that is part of the suite of instruments flown onboard the joint ESA and JAXA BepiColombo spacecraft, launched on October 20, 2018 and planned to enter Mercury orbit and begin observations in 2025. STROFIO will study and characterize the chemical composition and dynamics of Mercury's thin atmosphere

OTHER MISSIONS AND DATA ANALYSIS

(exosphere). Eight NASA-funded scientists serve as interdisciplinary scientists, guest investigators, or instrument co-investigators on the BepiColombo Science Team. These investigators collaborate with the BepiColombo team on a variety of projects that will improve understanding of both Mercury and Venus, as well their surrounding space environments.

Recent Achievements

The BepiColombo mission is currently in its cruise phase. It completed its second Venus flyby in August 2021 and the first of its six Mercury flybys in October of 2021. It will perform Mercury orbit insertion in December 2025. Optimization of the STROFIO sensors continues while the spacecraft travels to Mercury. A NASA-funded guest investigator leads a project combining observations from BepiColombo's ultraviolet spectrometer with telescopic observations from Earth to investigate the atmosphere and climate of Venus.

NEW FRONTIERS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Dragonfly	86.0	224.1	**390.4**	317.8	326.1	265.2	213.8
Other Missions and Data Analysis	64.9	64.6	**88.1**	97.2	127.6	144.4	187.3
Total Budget	**150.9**	**288.7**	**478.4**	**415.0**	**453.8**	**409.6**	**401.1**
Change from FY 2022 Budget Request			**189.7**				
Percent change from FY 2022 Budget Request			**65.7%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Near the end of its prime mission, the Juno spacecraft conducted the first flyby of Ganymede, (pictured above) within 700 miles of the largest moon in the solar system, since the Galileo mission ended twenty years ago. In its extended mission Juno will add observations of three of Jupiter’s large moons (Io, Europa, and Ganymede) to the growing body of scientific data it has collected. Europa and Ganymede are the targets of two upcoming missions by NASA (Europa Clipper) and ESA (Jupiter Icy Moons Explorer).Credit: NASA/Goddard/University of Arizona.

New Frontiers Program is a science program of medium - class spacecraft missions that performs high-quality Principal Investigator (PI)-led focused scientific investigations. Initiated in 2003, the New Frontiers Program pursues planetary science missions of moderate scope and high scientific priority and value. The program emphasizes competed and peer-reviewed missions accomplished under the leadership of the scientific research community and aligned with the scientific goals of the Planetary Science Decadal Survey.

Since its inception, the program has successfully launched three missions, one to study Pluto (New Horizons), a second to study Jupiter (Juno), and a third to return samples from the Bennu asteroid (Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer [OSIRIS-Rex]). A fourth mission to study the surface of Saturn's moon, Titan, is currently in formulation (Dragonfly).

The program also supports continued research and data analysis from its missions. The annual call for proposals competitively awards research grants based primarily upon their scientific merit. These grants not only broaden participation in the missions, but also deepen our understanding of the science objectives of each mission, produce new discoveries, and train the next generation of scientists.

The New Frontiers 4 Announcement of Opportunity (AO) had a mission cost cap of $850 million, excluding launch vehicle and mission operations costs.

NEW FRONTIERS

EXPLANATION OF MAJOR CHANGES IN FY 2023

The FY 2023 Dragonfly budget request supports an updated budget profile for the launch readiness date of no earlier than June 2027. The New Frontiers 5 Announcement of Opportunity (AO) is being accelerated from 2025 to no earlier than 2023.

ACHIEVEMENTS IN FY 2021

Download and analysis of the data from the 2019 New Horizons flyby of a small Kuiper Belt object, designated 2014 MU69 (now known as Arrokoth), continued through FY 2021. Due to the extreme distance between the New Horizons spacecraft and Earth, there is a very low communications rate and the download of data is slower than that of missions closer to Earth. The New Horizons spacecraft also conducted remote observations of several additional Kuiper Belt objects and together with the studies of Arrokoth, is giving us new insight into the building blocks of the solar system.

The Juno mission completed its prime mission in FY 2021 and has begun its extended mission. Analysis of Juno data is ongoing and has enabled significant progress in understanding the complex three-dimensional structure of Jupiter's atmosphere and interior structure. Mesmerizing images of Jupiter's clouds have not only enthralled the public but have enabled advances in our understanding of the planet's atmospheric dynamics, which are among the most complex in the solar system.

In October 2020, OSIRIS-REx successfully touched down at the primary sample collection site (called Nightingale), collected a sample of the asteroid regolith, and stowed the sample in the Sample Return Capsule. The spacecraft then executed a post-sampling reconnaissance pass over the Nightingale site in March of 2021, and successfully executed the Asteroid Departure Maneuver in May of 2021, placing the spacecraft in an Earth return trajectory. Entry, descent, and landing of the Sample Return Capsule will occur in September 2023.

The Dragonfly project continued in its preliminary design and technology completion phase (Phase B) throughout FY 2021, which included work on major science requirements and interface definitions as well as mobility tests with the project's integrated test platform (ITP) drone. The Dragonfly team conducted successful flights over a variety of terrain in FY 2021 with ITP, performing scouting flights, leapfrog flights, and various generic flights for data collection.

WORK IN PROGRESS IN FY 2022

The New Horizons mission will continue to downlink data and collect light curve measurements of distant Kuiper Belt objects. The mission is also characterizing the environment of this distant portion of the solar system. The team will prepare and submit a Senior Review proposal for its second mission extension.

Juno will extend the number of science passes of Jupiter and improve resolution of the complex spacing grid of magnetic field measurements of the planet. These measurements are invaluable as they reveal the interior magnetic structure of Jupiter, which is significantly different than expected. Juno will continue taking these measurements and will also be acquiring limited distant observations of Galilean satellites while in its extended mission phase.

OSIRIS-REx will continue in the Earth Return Cruise phase of the mission. During this phase, the science team will complete the preparations for the Sample Analysis phase of the mission, which will occur after the landing of the Sample Return Capsule in 2023.

NEW FRONTIERS

Dragonfly will continue its preliminary design, technology completion, and risk reduction activities throughout FY 2022.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

If approved through the Senior Review proposal submitted in FY 2022, New Horizons will continue in its extended mission phase throughout FY 2023.

The Juno mission will continue its approved extended mission, which continues to study Jupiter and some of its moons that are important in existing scientific studies.

After the entry, descent, and landing of OSIRIS-Rex's Sample Return Capsule, the sample material from the asteroid Bennu will be prepared for distribution and analysis, beginning a whole new phase of scientific research into these primitive bodies.

Dragonfly will continue its preliminary design and technology completion activities in preparation for Key Decision Point-C (KDP-C).

PROGRAM SCHEDULE

Date	Significant Event
Q1 FY 2023	Release of New Frontiers 5 Announcement of Opportunity (AO) solicitation
Q3 2025	Select fifth New Frontiers mission

PROGRAM MANAGEMENT & PLANNED CADENCE

The New Frontiers Program is a multi-project program, with responsibility for implementation assigned to the Planetary Missions Program Office, located at the Marshall Space Flight Center (MSFC).

The first three New Frontiers AOs have been released on an average cadence of every six-and-a-half years, and the delay in the Dragonfly launch date has extended the average launch cadence of all four missions in the program to seven years. The AO release and launch for the fifth mission will match this cadence.

ACQUISITION STRATEGY

NASA competitively selects New Frontiers missions, releasing AOs when available funding allows.

INDEPENDENT REVIEWS

NASA will schedule the New Frontier's next Program Implementation Review (PIR) when recommended by the primary stakeholders.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	MSFC	2016	PIR	Successful	TBD

DRAGONFLY

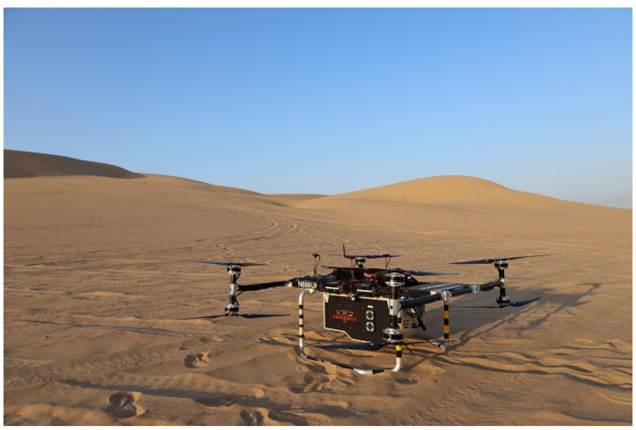
Formulation	Development	Operations

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**86.0**	**224.1**	**390.4**	**317.8**	**326.1**	**265.2**	**213.8**
Change from FY 2022 Budget Request			**166.3**				
Percent change from FY 2022 Budget Request			**74.2%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



Shown here is a Dragonfly prototype drone being tested in the field in Yuma, Arizona.

PROJECT PURPOSE

Dragonfly is a mission to study Titan, the largest moon of Saturn, using a rotorcraft carrying an advanced set of instruments to characterize the surface, atmosphere, and interior from different locations. Titan is a unique world that potentially harbors an interior ocean. Its surface, layered with organic snow on an icy crust possibly shaped by wind and fluvial processes, is important to study because it may be like early Earth, where carbon and nitrogen interacted with water and energy to form life. Through measurements at diverse locations across Titan, Dragonfly will characterize the habitability of Titan's environment; investigate how far pre-biotic chemistry has progressed; and search for chemical signatures indicative of water-based and/or hydrocarbon-based life.

EXPLANATION OF MAJOR CHANGES IN FY 2023

NASA rephased the budget profile from 2023 to 2027 to better support the launch readiness date of June 2027.

PROJECT PRELIMINARY PARAMETERS

Dragonfly will launch no earlier than 2027. Upon landing on Titan, Dragonfly will fly to dozens of locations looking for prebiotic chemical processes common on both Titan and Earth. Dragonfly, which has eight rotors and flies like a large drone, marks the first time NASA will fly a multi-rotor vehicle designed to collect science data on another planetary body. It will take advantage of Titan's dense

DRAGONFLY

Formulation	Development	Operations

atmosphere (four times denser than Earth's) and low gravity (one seventh that on Earth) to become the first vehicle ever to fly its entire science payload to multiple sites for repeatable and targeted access to surface materials. It is a scientifically diverse mission that includes an assortment of instruments: the Dragonfly Camera Suite (DragonCam), which is a set of microscopic and panoramic cameras to image Titan's terrain and scout for scientifically interesting landing sites; Dragonfly Gamma-Ray and Neutron Spectrometer (DraGNS), which consists of a deuterium-tritium Pulsed Neutron Generator and a set of a gamma-ray and neutron spectrometers to identify the surface composition under the lander; the Dragonfly Mass Spectrometer (DraMS), which is an advanced mass spectrometer to identify chemical components in surface and atmospheric samples, especially those relevant to biological processes; and the Dragonfly Geophysics and Meteorology Package (DraGMet), which is a suite of meteorological sensors including a seismometer.

Titan is an analog to the very early Earth and can provide clues to how life may have begun on our planet. During its nearly three-year baseline mission, Dragonfly will explore diverse environments from organic dunes to the floor of an impact crater where liquid water and complex organic materials, key to life, once existed together, possibly for tens of thousands of years. Its instruments will study how far prebiotic chemistry has progressed. They also will investigate the moon's atmospheric and surface properties and its potential subsurface ocean and liquid reservoirs. Instruments will search for chemical evidence of past or extant life. A multi-mission radioisotope thermoelectric generator will power the Dragonfly rotorcraft.

ACHIEVEMENTS IN FY 2021

Dragonfly continued preliminary design, technology development, and risk reduction activities throughout FY 2021, which included work on major science requirements and interface definitions as well as mobility tests with the project's integrated test platform (ITP) drone. The Dragonfly team conducted a variety of successful flights with the ITP, performing scouting flights, leapfrog flights, and various generic flights for data collection in preparation for Preliminary Design Reviews (PDR) in FY 2022.

WORK IN PROGRESS IN FY 2022

Dragonfly will complete subsystem and instrument level PDRs in preparation for the mission level PDR, expected to occur no earlier than September 2022.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

In FY 2023, Dragonfly will enter the implementation phase and work to mature its system design and prepare for the mission CDR in FY 2024.

ESTIMATED PROJECT SCHEDULE

Dragonfly's project schedule is based on a June 2027 launch readiness date.

DRAGONFLY

Formulation	Development	Operations

Milestone	Formulation Authorization Document	FY 2023 PB Request
PDR	N/A	Oct 2022
Key Decision Point-C (KDP-C)	N/A	Jan 2023
KDP-D	N/A	Feb 2026
KDP-E	N/A	May 2027
Launch	N/A	Jun 2027

Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

Life cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows the PDR.

KDP-B Date	Estimated Life Cycle Cost Range ($)	Key Milestone	Key Milestone Estimated Date Range
Jun 2019	$2.1B - 2.5B	Launch	Jun 2027

Project Management & Commitments

The Principal Investigator is from the Johns Hopkins University Applied Physics Laboratory (APL). APL has project management responsibility for Dragonfly.

Element	Description	Provider Details	Change from Formulation Agreement
Dragonfly Mass Spectrometer	Provides detailed analysis of organic chemistry	Provider: Goddard Space Flight Center (GSFC) Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Dragonfly Gamma-Ray and Neutron Spectrometer	Determines bulk near-surface composition and layering	Provider: APL Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

DRAGONFLY

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
Dragonfly Geophysics and Meteorology Package	Measures atmospheric conditions, seismicity, and surface/subsurface properties	Provider: APL Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Dragonfly Camera Suite	Documents landforms and processes, provides context for samples, and performs aerial imaging to scout landing sites	Provider: Malin Space Science Systems Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Drill for Acquisition of Complex Organics Sampling System	Provides pneumatic transfer system and sample acquisition drill	Provider: Honeybee Robotics Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Multi-Mission Radioisotope Thermoelectric Generator	Provides power to the Dragonfly lander	Provider: Department of Energy Lead Center: GRC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Cruise Stage	Propulsion stage to get Dragonfly to Titan	Provider: Lockheed Martin Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Entry, Descent, and Landing Assembly	Includes aeroshell, parachutes, and support equipment	Provider: Lockheed Martin Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Dragonfly Lander	Flight system to carry and support the science instruments	Provider: APL Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

DRAGONFLY

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: Dragonfly is not able to secure a test campaign window in the Transonic Dynamics Tunnel (TDT) by mission PDR as planned, Then: Dragonfly Mobility will not have reliable data to predict flight performance for mission PDR.	The project is continuing to work with NASA Langley Research Center and Headquarters personnel to schedule the Dragonfly test to a timeframe in 2022 that would mitigate the risk, which is contingent upon the TDT returning to full operations. The project is currently evaluating an opportunity to perform the testing in June 2022. Identifying any potential impacts to subsystem PDR readiness is part of this assessment.
If: The Dragonfly lander mass grows beyond the capabilities of the current mobility drive train, Then: The system will require redesign.	The lander integrated mechanical-thermal-mobility structure continues to evolve, with increasing mass of some parts, and the project is continuing work on a preliminary design. This includes a survey of mass reduction opportunities as well as an assessment of landing loads to explore alternate approaches to factors such as dampening. The project established an Engineering Advisory Board to help evaluate the design and to focus on overall mass margin. The APL Space Exploration Sector Chief Engineer is coordinating activities of available assets for this effort, including external partners.

Acquisition Strategy

NASA competitively selected the mission through the New Frontiers 4 Announcement of Opportunity (AO), and the final down selection was in June 2019. The major elements of the mission and spacecraft are as proposed to the AO.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
PI, Science Co-Is, Mission Management, Lander Development, DraGMet, DraGNS, System I&T, Science Operations, and Mission Operations	APL	Laurel, MD
Cruise Stage, Entry, Descent, and Landing (EDL) Assembly, and I&T Support	Lockheed Martin	Denver, CO

DRAGONFLY

Formulation	Development	Operations

INDEPENDENT REVIEWS

All dates are preliminary and subject to change.

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board (SRB)	Oct 2022	PDR	TBD	Critical Design Review (CDR)
Performance	SRB	Nov 2023	CDR	TBD	System Integration Review (SIR)
Performance	SRB	Jan 2026	SIR	TBD	Operational Readiness Review (ORR)
Performance	SRB	Feb 2027	ORR	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
New Frontiers Future Missions	2.2	1.9	**2.5**	9.0	54.3	94.5	119.9
New Frontiers Research	4.9	10.4	**10.5**	10.5	9.3	9.3	9.5
Origins Spectral Interpretation Resource	10.4	11.1	**32.1**	36.8	25.4	20.0	32.4
New Horizons	12.5	9.5	**12.5**	12.5	12.5	12.5	12.5
Juno	35.0	31.8	**30.5**	28.4	26.2	8.1	13.0
Total Budget	**64.9**	**64.6**	**88.1**	**97.2**	**127.6**	**144.4**	**187.3**
Change from FY 2022 Budget Request			**23.5**				
Percent change from FY 2022 Budget Request			**36.4%**				

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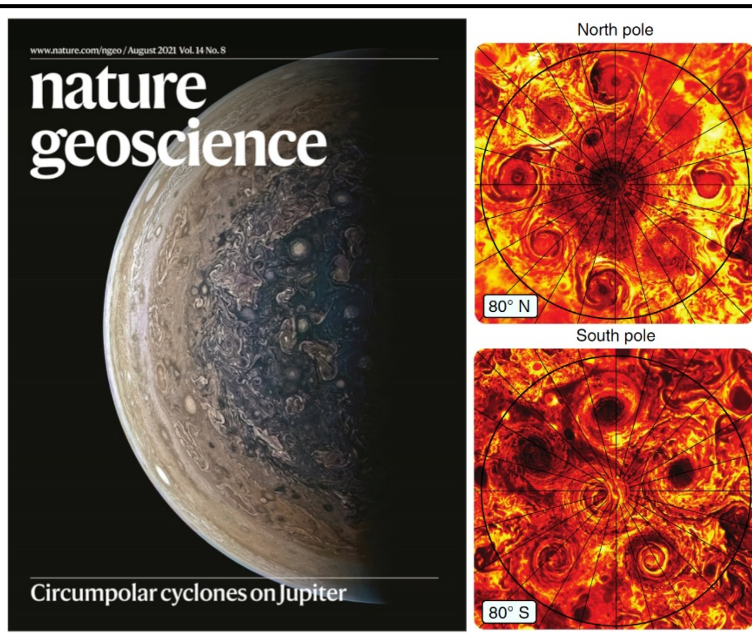

Pictured here is the cover of Nature Geoscience August 2021. JIRAM observations of Jupiter's north and south poles showing each pole contains a polar cyclone. Until now it was unclear why the north pole holds eight circumpolar cyclones (CPCs) and the south pole has five CPCs. Credit: Gavriel and Kaspi (2021).

New Frontiers Other Missions and Data Analysis includes support for three operating missions: New Horizons; Juno; and Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx), analysis of data from these missions, and preparation for future missions.

Mission Planning and Other Projects

NEW FRONTIERS FUTURE MISSIONS

New Frontiers Future Missions supports technology development for future missions and provides the funding required for the next announcement of opportunity (AO). NASA will accelerate the next AO from 2025 and release it no earlier than FY 2023.

OTHER MISSIONS AND DATA ANALYSIS

NEW FRONTIERS RESEARCH

New Frontiers Research funds analysis of archived data from New Frontiers missions as well as participating scientists and selected members of the research community, who augment and enhance the science teams of New Frontiers missions. New Frontiers Research provides the research community access to data and samples, enabling research to continue for many years after mission completion. Participating scientists bring new ideas to mission teams and frequently provide a pathway for early career investigators to gain experience with planetary missions. This program supports efforts to maximize science return from each of the missions. NASA solicits planetary research proposals from the United States planetary science community and evaluates them for selection through competitive peer review. NASA will select new research in FY 2022 using the New Horizons mission data returned from the Pluto system, Juno mission data returned from Jupiter, and OSIRIS-REx mission data returned from the asteroid Bennu.

NASA will make selections early in CY 2023 from the New Frontiers Data Analysis program proposals solicited for funding in FY 2022. A new program element group for OSIRIS-REx Sample Analysis Participating Scientists will join and enhance the OSIRIS-REx sample analysis activities, which will commence after the sample arrives in September 2023.

Recent Achievements

The New Frontiers Data Analysis program element competitively selected and awarded 15 new science investigations. These investigations use data provided by all New Frontiers missions to expand the scientific results generated by the mission science team. Three of these new projects are investigating the surface of asteroid Bennu and mapping it in unprecedented detail from the OSIRIS-REx mission. These investigations will help pave the way for analyzing samples from Bennu's surface.

The Planetary Science Division (PSD) completed the evaluation of proposals submitted to a call for participating scientists on the Juno mission. The objective of the Juno Participating Scientist Program (PSP) is to enhance the scientific return of the Juno extended mission through new investigations that broaden and/or complement existing mission objectives, while also providing planetary scientists the experience to serve on a NASA space mission and science team. PSD received 27 proposals and made 10 selections in November 2021.

Operating Missions

NEW HORIZONS

New Horizons is the first scientific investigation to obtain close observations of Pluto and its moons, Charon, Nix, Hydra, Kerberos, and Styx. Scientists discovered the last four moons after the spacecraft launch in 2006. New Horizons visited the Kuiper Belt Object (KBO) Arrokoth (2014 MU69), found eight years after launch using the Hubble Space Telescope. Arrokoth is in a region approximately two billion miles beyond Pluto's orbit and is the most unaltered piece of early solar system ever explored by a spacecraft. Research thus far indicates it likely formed through a gentle, low speed merger of two objects that spiraled towards each other as they orbited one another. Scientists aim to find answers to basic questions about the surface properties, geology, interior makeup, and atmospheres of these bodies, and their relationship to solar system formation.

OTHER MISSIONS AND DATA ANALYSIS

New Horizons launched on January 19, 2006. It successfully encountered Pluto on July 14, 2015 and completed downloading all the primary science observations of the Plutonian System in October 2016. New Horizons completed a fly-by of Arrokoth on January 1, 2019. The mission is currently in extended operations through September 2022.

Recent Achievements

On April 17, 2021, New Horizons crossed the 50 Astronomical Unit (AU), which is more than 4.5 billion miles, threshold making it one of few missions to reach this enormous distance from our home planet. The spacecraft continues to explore this previously unvisited area of our solar system and beyond. The mission completed software uploads in 2021 that provide new capabilities for the instruments on-board and will enhance the science return. The project continues to gather data on the plasma environment of the Kuiper Belt and to obtain light curves of distant KBOs. The ground-based search to find additional KBOs to potentially study is unveiling new objects that New Horizons will pass closest to many years from now, much farther out than previously predicted.

The mission has provided insight into processes that have shaped the Pluto heart-shaped basin, Sputnik Planitia, and illustrated how the two lobes of the KBO Arrokoth formed at approximately the same time and/or evolved together.

The mission team discovered two KBO binaries (2011 JY31 and 2014 OS39) in 2021 using the Long Range Reconnaissance Imager instrument. They also authored a book, published in July 2021, which is a compendium of everything known about the Pluto system thus far. The mission team also processed an image of the dark side of Pluto, its south pole, which is in a decades-long winter but still illuminated by sunlight reflecting from its moon, Charon.

JUNO

Juno has transformed our view of Jupiter, the largest, most massive planet in the solar system, through significant discoveries about its atmospheric dynamics and composition, interior structure, origin, and evolution. Juno launched on August 5, 2011 and entered Jupiter's orbit on July 4, 2016. The project recently celebrated its 10th launch anniversary, and the spacecraft is in its sixth year of operations in the Jovian system. Juno’s state-of-the-art instruments gather information from deep in Jupiter’s atmosphere, enabling scientists to unveil the planet's properties beneath its top cloud layer. Juno began its extended mission phase in August 2021 and will continue investigations through September 2025, including close passes of Jupiter’s north polar cyclones, flybys of the moons Ganymede, Europa, and Io, as well as the first examination of the faint rings encircling the planet.

Recent Achievements

Juno has completed 37 of 76 planned orbits around Jupiter, which currently last 43 days but will eventually transition to ~33 days. During these science operations, Juno is sampling Jupiter’s full range of latitudes and longitudes during polar orbits and capturing details no other mission has captured before. For instance, the spacecraft recently used its Jovian Infrared Auroral Mapper (JIRAM) instrument during flybys of Jupiter’s moon Ganymede to create the latest infrared map, combining data from three flybys, including its latest approach on July 20, 2021. Juno’s unique polar views and closeups of Ganymede are building upon observations by NASA’s previous explorers Voyager, Galileo, New Horizons, and Cassini.

Juno scientists discovered circumpolar cyclones (CPC) structures on Jupiter in 2017, with eight CPCs in the north pole and five CPCs in the south pole, but an explanation for such an arrangement had remained a mystery until this past year. In 2021, Juno scientists gained new insight into the CPCs by using analytical methods that explain the location, stability, and number of the CPCs by establishing the primary forces that act on these massive storms. Furthermore, after four years of Juno/JIRAM observations, Juno researchers also discovered major properties of these circumpolar structures: they spin slowly but at different rates (the south one spins twice as fast as the north one), both structures (characterized by a total of 15 singular cyclones) are extremely stable, the cyclones have similar intrinsic oscillation frequencies, and perturbations seem to propagate from one cyclone to the next closest one.

OSIRIS-REx

OSIRIS-REx is the first United States mission to bring a sample from an asteroid back to Earth. The OSIRIS-REx spacecraft traveled to Bennu (asteroid 101955), a near-Earth carbonaceous asteroid formerly designated 1999 RQ36, studied the asteroid in detail and is bringing a sample (at least 60 grams or 2.1 ounces) back to Earth. Analysis of this sample by current and future generations of scientists will yield insight into planet formation and address questions we have not thought of yet. The data collected at Bennu will aid in further understanding asteroids that could collide with Earth. In addition, the mission will measure the Yarkovsky effect on a potentially hazardous asteroid and determine the asteroid properties that contribute to this effect. The Yarkovsky effect is a small force on an asteroid caused by the Sun as the asteroid absorbs sunlight and re-emits that energy into space as heat.

OSIRIS-REx launched on September 8, 2016 and arrived at Bennu on December 3, 2018. The mission globally mapped the surface from distances of less than half a mile to about three miles. The spacecraft cameras and instruments photographed the asteroid and measured its surface topography, composition, and thermal emissions. Radio science provided mass and gravity field maps. This information helped the mission team select the most promising locations to collect a sample of pristine asteroid material.

Recent Achievements

In FY 2021, the OSIRIS-REx spacecraft successfully descended to the surface of Bennu, contacted the surface, collected a sample, and backed away. Following analysis of the sampling head, NASA determined that the spacecraft had likely collected an adequate amount of material and then stowed the sample for secure return to Earth. The spacecraft then conducted a post sampling reconnaissance pass over the sample site, and successfully executed the Asteroid Departure Maneuver, placing the spacecraft on an Earth return trajectory. To deliver the sample to Earth, OSIRIS-REx has a capsule similar to the one that returned the sample of Comet 81P/Wild on the Stardust spacecraft.

OSIRIS-Rex will be on its return cruise through all of FY 2022. During the cruise phase the team will plan and rehearse curation and sample return analysis activities to implement once the sample is delivered to Earth The OSIRIS-REx spacecraft is due to reach Earth September 24, 2023. Upon return, the capsule containing pieces of Bennu will separate from the rest of the spacecraft and enter Earth’s atmosphere. The capsule will parachute to the Utah Test and Training Range in Utah's West Desert, where scientists will retrieve it.

MARS EXPLORATION

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Other Missions and Data Analysis	339.5	270.7	**233.9**	223.8	211.7	226.8	242.1
Total Budget	**339.5**	**270.7**	**233.9**	**223.8**	**211.7**	**226.8**	**242.1**
Change from FY 2022 Budget Request			**-36.8**				
Percent change from FY 2022 Budget Request			**-13.6%**				

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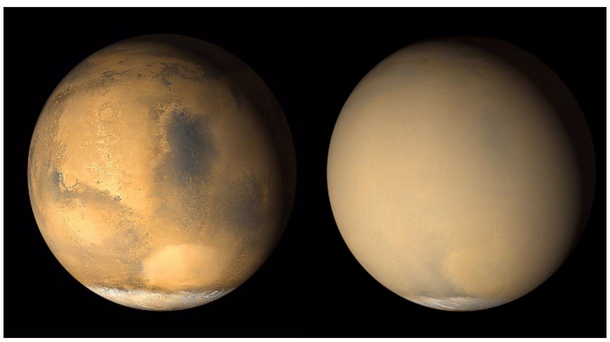

In 2018, Mars orbiters and rovers on the surface measured a global dust storm, shown above are images or Mars. This unprecedented combination of measurements is still providing tremendous insight into the effects of dust on the atmosphere. Dust heats and expands the atmosphere and boosts the loss of water into space. The global dust storm blotted out sunlight on the surface and ended the solar powered Opportunity rover mission, which had been operating for over 14 years.

The Mars Exploration Program seeks to understand when Mars may have had habitable conditions for microbial life, whether Mars has supported microbial life in the past or today, and the extent to which Mars could be a habitable world for humans in the future. As the most Earth-like planet in the solar system, Mars has a landmass approximately equivalent to the Earth's, as well as ancient remnants of many of the same geological features, such as riverbeds, river deltas, and volcanoes. Mars also has many of the same "systems" that characterize Earth, such as air, water, ice, and geology that all interact to produce the Martian environment. Mars also has fundamental differences from Earth including the lack of a global magnetic field and chaotic changes in the orientation of its spin axis over tens of millions of years, which have affected its environment.

Individual orbital and landed robotic missions have progressively built on the discoveries of each mission, all collectively guided by four broad, overarching goals for Mars Exploration:

- Determine if life ever arose on Mars;
- Characterize the climate of Mars;
- Characterize the geology of Mars; and
- Prepare for human exploration.

Today, our robotic scientific missions are paving the way for a future in which humans and robots will together explore Mars and the solar system.

MARS EXPLORATION

EXPLANATION OF MAJOR CHANGES IN FY 2023

NASA has added funding to the Mars Rover 2020 budget to complete its prime mission and support extended operations from FY 2024-2026.

Due to the need to fund higher priorities, including to cover cost growth expected from the Mars Sample Return mission, the budget terminates NASA financial support for the Mars Ice Mapper, which is still in pre-formulation with roles being discussed with international partners. NASA had not planned on making hardware contributions to this mission but had discussed the possibility of taking on mission management activities.

The Mars Sample Return mission is funded in a separate project line and is covered later in the congressional budget justification.

OTHER MISSIONS AND DATA ANALYSIS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Mars Ice Mapper	0.0	8.5	**0.0**	0.0	0.0	0.0	0.0
Mars Organic Molecule Analyzer (MOMA)	5.1	4.9	**6.2**	3.7	4.0	3.0	0.0
Mars Rover 2020	155.0	105.7	**80.0**	70.0	60.0	60.0	60.0
ExoMars	2.1	2.0	**2.0**	2.0	2.0	2.0	2.0
Mars Program Management	12.8	10.9	**10.9**	9.6	13.2	15.3	13.3
Mars Future Missions	23.3	8.1	**6.4**	15.6	13.6	32.0	57.4
Mars Mission Operations	6.8	6.7	**5.5**	5.5	5.5	5.6	5.4
Mars Research and Analysis	14.4	15.1	**15.7**	15.7	15.7	15.7	15.7
Mars Technology	10.1	8.5	**2.5**	3.0	3.0	3.0	3.1
2011 Mars Science Lab	48.9	43.3	**45.0**	40.0	35.0	30.0	25.0
Mars Reconnaissance Orbiter 2005 (MRO)	28.3	24.4	**25.5**	24.5	24.5	25.0	25.0
Mars Odyssey 2001	11.4	10.5	**11.0**	11.0	11.0	11.0	11.0
Mars Express	0.3	0.0	**0.3**	0.3	0.3	0.3	0.3
Mars Atmosphere & Volatile EvolutioN	21.0	22.0	**23.0**	23.0	24.0	24.0	24.0
Total Budget	**339.5**	**270.7**	**233.9**	**223.8**	**211.7**	**226.8**	**242.1**
Change from FY 2022 Budget Request			**-36.8**				
Percent change from FY 2022 Budget Request			**-13.6%**				

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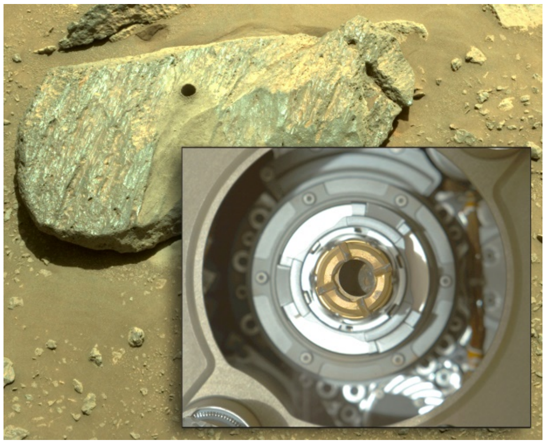
OTHER MISSIONS AND DATA ANALYSIS



Images taken by the Mars 2020 Perseverance rover's Navigation Camera and Mastcam-Z camera (inset) confirmed the successful acquisition of the first rock sample the Mars Sample Return campaign collected. The core can be seen in the sample tube held in the drill bit at the end of the rover's robotic arm. Credit: NASA/JPL-Caltech

Other Missions and Data Analysis includes mission planning and management, small missions in development, research and technology activities, funding for future Mars missions, and Mars operating missions. The operating projects include: Mars Science Laboratory (MSL), Mars Reconnaissance Orbiter 2005 (MRO), Mars Odyssey 2001, Mars Express, Mars Atmosphere and Volatile Evolution (MAVEN), and Mars Rover 2020.

Mission Planning and Other Projects

MARS ORGANIC MOLECULE ANALYZER (MOMA)

The ExoMars Rover mission is the second of the European Space Agency (ESA) ExoMars missions and will carry the "Rosalind Franklin" rover to the surface of Mars. MOMA is the core astrobiology instrument on the rover, and it addresses the top ExoMars science goal of seeking signs of past or present life on Mars. NASA provided the MOMA-Mass Spectrometer (MOMA-MS), a subsystem of MOMA. It is primarily a dual-source mass spectrometer, including laser desorption capability, used to detect a wide-range of organic molecules in Martian samples. Organic structure and distribution can be indicators of past or present life. ESA moved the launch date from 2020 to October 2022.

Recent Achievements

NASA provided support for the testing and validation of the MOMA instrument in the final flight configuration integrated with the ExoMars rover and provided support to ESA for testing the spacecraft parachute system.

MARS PROGRAM MANAGEMENT

Mars Program Management provides for the broad-based implementation and programmatic management of the Mars Exploration Program. Mars Program Management also supports independent review panels, planetary protection studies, advanced mission and program architecture studies, program science, and telecommunications coordination and integration.

MARS FUTURE MISSIONS

Mars Future supports the planning and design studies for a future sample receiving facility for samples returned from the Mars Sample Return project. NASA requires a Biosafety Level-4 (BSL-4) rated facility

OTHER MISSIONS AND DATA ANALYSIS

and studies now underway will guide the decision on what form the facility will take. NASA is exploring various options, including the possibility of utilizing existing Government facilities.

MARS MISSION OPERATIONS

Mars Mission Operations provides management and leadership for the development and operation of Mars multi-mission systems for operations. Mars Mission Operations supports and provides common operational systems and capabilities at a lower cost and risk than having each Mars project produce systems individually.

MARS RESEARCH AND ANALYSIS (R&A)

Mars R&A provides funding for research and analysis of Mars mission data to understand how geologic, climatic, and other processes have worked to shape Mars and its environment over time, as well as how they interact today. The project has invested in Mars data analysis capabilities to analyze archived data collected from Mars missions, as well as critical products that provide data and analyses for the safe arrival, aero-maneuver, entry, descent, and landing on Mars.

Data analysis through Mars R&A enables a much broader and objective analysis of the data and samples. It also allows research to continue for many years after mission completion. These research projects increase our scientific understanding of Mars's past and present environments, disseminating the results through the scientific publications. By using data collected by spacecraft, researchers can make scientific discoveries and test hypotheses about the Martian environment.

Recent Achievements

Recently published papers have provided significant new information on a multitude of varied research areas. New insight into the carbon dioxide deposits in the south pole reveal the deposits may be remnants of more massive deposits that formed during a period half a million years ago of lower axial tilt. Axial tilt is the angle between an object's rotational axis and its orbital axis, which is the line perpendicular to its orbital plane. Analysis of "perihelion cloud trails" (PCT) show the PCTs form by strong solar heating of rough terrain that results in a highly turbulent atmosphere; gravity waves (GW) travel higher in the atmosphere and cool air locally enough for clouds to form. The cloud particles then rapidly transport to the west in Mars's tropical jet stream, forming a long cloud. Data comparing the similar age and distribution of craters with alluvial fans in the southern mid-latitudes have shown them to be consistent with a late occurring, widespread (rather than local) source of water. Craters with deltas are preferentially located at lower elevations where interactions with groundwater may have enabled the formation and persistence of lakes. These landforms are more numerous and widespread than previously reported. Further observations of the western Arabia Terra support the idea that explosive calderas exist, and they produced thousands of super eruptions spread out over 500 million years of ancient Mars history.

MARS TECHNOLOGY

Mars Technology focuses on technological investments that lay the groundwork for successful future Mars missions, such as: entry, descent, and landing capabilities; science helicopter capability (scale-up

OTHER MISSIONS AND DATA ANALYSIS

from Ingenuity to support science instruments); Mars ascent vehicle components; sample handling and processing technologies; and surface-to-orbit communications improvements.

Recent Achievements

Recent investments in Mars technology resulted in the hugely successful Mars Helicopter technology demonstration. The Ingenuity helicopter technology demonstration goal was to take five flights in 30 Martian days. Ingenuity transitioned from a pure technology demonstration to operations and has now survived more than 245 Martian days and completed over 18 flights. Ingenuity is performing scouting missions for Perseverance that significantly optimize the exploration of Jezero crater and create valuable time savings in performing Mars science.

Prior investments in Mars technology enabled the Mars 2020 Perseverance rover's robotic sample caching system, which successfully collected, sealed, and stored its first set of rock core samples of Mars in tubes that it will later deposit on the Martian surface for retrieval by a future mission.

Operating Missions

MARS ROVER 2020

NASA's Mars Rover 2020 Perseverance rover will advance one of the top scientific priorities detailed in the National Research Council's Planetary Science Decadal Survey for 2013-2022, initiating the first leg of a round trip to Mars to return samples to Earth for further study. Perseverance is characterizing the planet's geology and past climate, searching for signs of ancient microbial life on Mars, collecting and storing carefully selected rock and sediment samples, and testing new technologies to benefit future robotic missions and pave the way for human exploration of Mars. Subsequent NASA missions, in cooperation with ESA, will send spacecraft to Mars to retrieve the sealed samples collected by Perseverance from the surface of Mars and return them to Earth for in-depth analysis.

The Perseverance rover is carrying a competitively selected science and technology instrument payload of seven instruments. Five of the instruments provide the clearest possible measurements for seeking possible signs of ancient life (potential "biosignatures") on Mars over its 4.6 billion-year history. The remaining two instruments assess environmental hazards and resources for future human exploration. Perseverance also ferried a helicopter named Ingenuity, the first aircraft to achieve powered, controlled flight on another planet. The Mars 2020 mission incorporates new capabilities developed through investments by NASA's Space Technology Mission Directorate and Human Exploration and Operations Mission Directorate and payload contributions from international partners.

Recent Achievements

The Mars Rover 2020 mission safely landed the Perseverance rover on the surface of Mars at Jezero Crater on February 18, 2021. Improvements in entry, descent, and landing capabilities, including the infusion of Terrain Relative Navigation, enabled the landing at the scientifically compelling, yet challenging terrain of Jezero Crater.

Six months after landing, Perseverance successfully collected its first set of rock samples. Analysis of observation data for the sample site indicates the level of alteration in the analyzed rocks suggests that

OTHER MISSIONS AND DATA ANALYSIS

groundwater was present for a long time in Jezero Crater - an indication that a potentially habitable environment was sustained for a substantial period of time. The science team began archiving returned data into NASA's Planetary Data System (PDS) and publishing campaign results.

In the initial months of surface operations, the mission team completed the science instrument and payload commissioning phase. During commissioning, the mission team accomplished the first demonstration of in situ resource utilization on another planet (generating oxygen from the Martian atmosphere with the MOXIE instrument) and successfully completed test flights for the Ingenuity helicopter technology demonstration phase. After completing the technology demonstration phase, Ingenuity began the surface operations demonstration phase to provide scouting support to the Perseverance science mission.

Perseverance's first science campaign has explored Jezero's deepest (and most ancient) layers of exposed bedrock and other intriguing geologic features through a series of geologic units. The first unit, called "the Crater Floor Fractured Rough," is the crater-filled floor of Jezero. The adjacent unit, named "Séítah" (meaning "amidst the sand" in the Navajo language), includes Mars bedrock but is also home to ridges, layered rocks, and sand dunes. The goal of this first campaign is to determine which locations in these units reveal Jezero Crater's early environment and geologic history, and to then collect rock samples at those determined locations.

Additionally, the mission utilized two microphones aboard the Perseverance to record nearly five hours of Martian wind gusts, rover wheels crunching over gravel, and motors whirring as the rover moved its arm.

EXOMARS

The ESA ExoMars program is a series of two missions designed to understand if life ever existed on Mars. The first mission in the ExoMars program is the 2016 ExoMars Trace Gas Orbiter (TGO), which launched in March 2016 and began its science and relay operations phase in March 2018, starting with the observations of the global dust storm. For this mission, NASA contributed two Electra ultra-high frequency (UHF) telecommunication radios, identical to those used successfully on NASA's MRO and MAVEN. The Electra radio acts as a communications relay and navigation aid for surface assets and support navigation, command, and data-return needs for landers and rovers. Furthermore, two instruments, the Colour and Stereo Surface Imaging Systems (CaSSIS) and the Nadir and Occultation for MArs Discovery (NOMAD) have significant contributions from U.S. co-investigators.

Recent Achievements

Researchers observed hydrogen chloride for the first time in the Martian atmosphere and made the first ever infrared observations. The first detections of vertically resolved profiles of CO allow tracking of the important chemical interactions. The CaSSIS camera, with significant participation from U.S. co-investigators, continues its imaging of the surface and has now made more than 22,000 images, including more than 1,500 stereo observations. Most of the stereo observations help synthesize three-dimensional landscape models of the surface of Mars.

The ExoMars Trace Gas Orbiter, using the contributed NASA Electra radio, is relaying over 55 percent of the science data and images from NASA's Curiosity rover, InSight lander, and the newly arrived Perseverance rover. This highly successful international collaboration has proven key to achieving the

OTHER MISSIONS AND DATA ANALYSIS

mission objectives of Perseverance, including helping enable the collection of the first rock samples on the surface of Mars as part of the Mars Sample Return campaign, aiding command and telemetry data transfers with the Ingenuity helicopter, and returning the vast number of images to engage with and excite the public.

2011 MARS SCIENCE LAB (MSL)

MSL and its Curiosity rover, which successfully landed in August 2012, completed its prime mission exploration activities in 2014. Now in extended mission, the Curiosity rover is exploring and quantitatively assessing regions on Mars as potential past habitats for life and has determined that Mars, at least at one point in time, was able to support microbial life. The Curiosity rover is collecting Martian soil and rock samples and analyzing them for organic compounds and environmental conditions that could have supported microbial life, and measuring the Martian atmosphere, the radiation environment, and the weather. MSL is the first planetary mission to use guided entry landing techniques, steering itself toward the Martian surface. This landing method enabled the rover to target, and successfully land, in an area less than 12 miles in diameter, about one-sixth the size of previous landing zones on Mars. This landing system is the basis of the system architecture for the Mars 2020 mission and enabled the targeting of the more challenging terrain in Jezero crater.

Curiosity is the first planetary rover to make use of a nuclear power source, which gave the rover the ability to travel up to 12 miles during the two-year primary mission. This international partnership mission uses components provided by the space agencies of Russia, Spain, France, and Canada.

Recent Achievements

Curiosity has traveled over 16.4 miles (26 km) since landing and has been exploring the lower reaches of Mount Sharp, the prime science target of the mission, and is now in its third extended mission period. Over the course of this extended mission, the rover is closely investigating the higher regions of the clay-sulfate transition, crossing through the Greenhugh Pediment and Gediz Vallis Ridge, and entering the sulfate unit. Each unit represents a distinct ancient environment, or change in environment, and each has the potential for groundbreaking advances in understanding Mars’ ancient climate. The rover's traverse is enabling investigation of the transition from clay to sulfate-bearing layers on Mount Sharp that may record a regional or global change from a wetter to a drier climate. The clay-sulfate transition region has an increase in the frequency and diversity of post-depositional features, such as bumps, spots, veins, and nodules. The nature and composition of these features reveal how fluids interacted with these rocks, what the environment was like, and where the fluids originated.

Overall, the rover is healthy and operating nominally during this mission extension. The rover team is closely monitoring the condition of the wheels, which have driven well beyond their expected design distance. To date, three grousers have broken on the left middle wheel and a single grouser has broken on the right middle wheel. This level of wear is consistent with wear trending and system predictions. Given the current distance driven and wheel condition, the total wheel expected life estimate is at 26 miles (42 km) and sufficient for the full extended mission lifetime.

OTHER MISSIONS AND DATA ANALYSIS

MARS RECONNAISSANCE ORBITER 2005 (MRO)

MRO, currently in its fifth extended operations phase, carries the most powerful camera ever flown on a planetary exploration mission: The High-Resolution Imaging Science Experiment (HiRISE). This capability provides a more detailed view of the geology and structure of Mars and is critical in identifying obstacles that could jeopardize the safety of future landers and rovers. A second camera, The Context Camera (CTX), acquires medium-resolution images that provide a broader geological context for the more detailed observations from higher-resolution instruments; it has covered most of the planet and searches for new phenomena, such as new impact craters, revealing subsurface ice. MRO also carries a radar sounder to find subsurface water ice, an important consideration in selecting scientifically worthy landing sites for future exploration.

MRO carries a high-resolution imaging spectrometer, the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM), which can map minerals at unprecedented spatial resolution. A wide-angle camera, the Mars Color Imager (MARCI), provides daily global weather maps, and the Mars Climate Sounder (MCS) shows how the Martian atmosphere transports dust and water vapor. MRO will follow up on recent discoveries of an increasingly diverse array of ancient aqueous environments and buried carbon dioxide ice that, if released, would double the present atmospheric pressure. MRO will extend mapping of the three-dimensional structure and content of the polar ice deposits, characterize the episodic nature of great dust storms, expand coverage of surface changes, and monitor possible seasonal surface color changes suggestive of liquid water flow on Mars today. MRO characterized the landing sites for the Mars 2020 Rover and the 2022 ESA ExoMars Rover.

As it explores Mars, MRO also serves as a major element of an “interplanetary Internet,” as a relay communications orbiter relaying commands to and data from the Curiosity and Mars 2020 Perseverance rovers and the InSight lander to Earth. In FY 2021, MRO will continue to characterize phenomena on the surface of Mars, such as the Recurring Slope Lineae and dust storms. In addition, MRO relayed to Earth the entry, descent, and landing telemetry from Mars 2020 during its landing in February of 2021.

Recent Achievements

During its fifth extended mission (FY 2020- FY 2022), MRO has continued pursuing its science goals while supporting the successful landing of Perseverance in February 2021. MRO provided "bent-pipe" relay of telemetry from Perseverance in near-real time, and HiRISE acquired a snapshot of the landing craft and its parachute during the final leg of its descent to the surface. Since then, HiRISE continues to image areas disturbed by the rovers and their traverses for scientific purposes. Having reversed the spacecraft drift to later local times required to cover the Perseverance landing, MRO has resumed its change detection campaign using CTX and HiRISE, including the identification of new impact craters, some exposing icy bottoms.

MCS and MARCI observed patterns of low latitude cloudiness and polar cap evolution during this Martian northern spring and summer typical of past Mars years. The major dust storms period starts in March, and MARCI will continue its dust storm alerts for the solar-powered InSight and other surface missions. HiRISE detected a few more ground ice cliff exposures at high latitudes, but fewer ice block falls at the edge of the north polar cap than in earlier years. CTX took advantage of a rare, relatively dust-free atmosphere over the Hellas Basin this year to acquire much improved survey data of the basin floor and its intriguing geomorphic features. Researchers used the Shallow Subsurface Radar captured radar and imaging data from multiple missions to map probable locations of subsurface ice at depths of a few

OTHER MISSIONS AND DATA ANALYSIS

meters or more; mapping results were reported as part of a Subsurface Water Ice Mapping (SWIM) project.

MCS began the second phase of its campaign to detect more shallow subsurface ice as measured through ground temperatures. Previous MCS data cited in a National Academies of Sciences, Engineering, and Medicine report could possibly relax Planetary Protection restrictions for some landing missions on Mars. Imaging of hundreds of dust-devil tracks across the long narrow streaks known as Recurring Slope Lineae (RSL) formed after the last planet-wide dust storm point more to RSL being dry flows of dust and sand driven by near-surface winds, rather than water activity. Studies using MCS, MAVEN and TGO data revealed enhanced loss of water to space when major dust storms warmed the Martian middle atmosphere, thus forcing water vapor to move to higher altitudes.

MARS ODYSSEY 2001

Mars Odyssey, currently in its eighth extended mission operations phase, continues in orbit to explore Mars with its powerful set of instruments, and provides a key element of the communications infrastructure for landed assets. From its unique morning orbit, Odyssey's Thermal Emission Imaging System (THEMIS) is observing frost, clouds, and fogs that no other orbiter can see. It sends information to Earth about Martian geology, climate, and mineralogy. Measurements by Odyssey enable scientists to create maps of minerals and identify regions with near-surface water associated with hydrated minerals or ice. Observations that measure the surface temperature provide spectacular images mapped onto Martian topography. Mars Odyssey will continue critical, long-term longitudinal studies of the Martian climate. Odyssey has served as an essential link in communications between Earth and NASA's surface assets on Mars for more than a decade. Starting in November 2018, Odyssey has provided crucial relay support for the InSight lander.

Recent Achievements

Odyssey team scientists are studying the details of Martian weather and climate, revealing the current cycles of water and dust, and mapping terrains that once were potentially hospitable to life. The surface geophysical observatory mission, InSight, relies on daily contacts with Odyssey to conduct its search for Mars quakes and studies of the interior structure of the planet. Odyssey also provides frequent data relay services for the Perseverance rover. Odyssey completed its THEMIS observing campaign of the Martian moon Phobos. Thermal emission data provided information about the surface texture, structure, and composition of surface materials. Odyssey and THEMIS coordinated a series of maneuvers to observe the volcano Apollinaris Patera at eight different roll angles over a period of one month. The data should reveal the effects of surface roughness at sub-pixel scales on THEMIS infrared signatures.

MARS EXPRESS

Mars Express, currently in its eighth extended mission operations phase, is an ESA mission that provides an understanding of Mars as a “coupled” system: from the ionosphere and atmosphere down to the surface and sub-surface. This mission addresses the climatic and geological evolution of Mars as well as the potential for life on the planet. NASA contributed components for the Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) and Analyzer of Space Plasmas and Energetic Atoms (ASPERA) instruments aboard Mars Express and participates in the scientific analysis of mission data.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

The Mars Express MARSIS instrument continued investigations with both subsurface soundings and upper atmosphere/ionosphere observations. Due to the prioritization of other Mars science investigations, NASA directed that the majority of NASA participation in the Mars Express mission conclude at the end of FY 2020, and the remaining collaboration with the MARSIS instrument investigations conclude at the end of FY 2021. The team is calibrating the data acquired during the mission and placing it into the Planetary Data System. The current budget supports the Deep Space Network costs to continue communications for the ESA-operated instruments.

MARS ATMOSPHERE AND VOLATILE EVOLUTION (MAVEN)

MAVEN, now in its fourth extended mission, launched in 2013 and successfully completed its primary mission in November 2015. MAVEN is the first mission devoted to studying Mars' upper atmosphere, with the most comprehensive measurements ever taken to address key scientific questions regarding the loss of the Mars atmosphere, liquid water, and habitability. The instrumentation suite allows scientists to observe the upper atmosphere, ionosphere, solar energetic drivers, and magnetic fields, to determine how Mars’ atmosphere evolved through time. These measurements of how the Martian atmosphere responds to the sun’s radiation and intense solar storms are critical for understanding the history of water. While geological and geomorphic evidence shows that oceans of water once existed on Mars, we now know through MAVEN that much of that water slowly evaporated as the atmosphere eroded over time. Thus, the mission is answering long-standing questions regarding the loss of the Mars atmosphere, liquid water, and habitability. Scientists are also using MAVEN data to determine the role that loss of volatile compounds (e.g., carbon dioxide, water) from the Mars atmosphere to space has played through time, and the importance of this loss in changing the Mars atmosphere and climate through time.

As with all Mars Exploration Program orbiters, MAVEN carries an Electra radio for communications with rovers and landers on the Martian surface. MAVEN has carried out relay activities and began transmitting much higher volumes since 2019 after the spacecraft adjusted its orbit to serve as a more efficient relay.

Recent Achievements

MAVEN recently completed seven years of orbiting Mars. This extended period of measurements has allowed MAVEN scientists to determine that the global dust storms on Mars remove water from the atmosphere twice as much as during quiet (non-dusty) conditions. This changes the paradigm of the basic hydrological cycle on Mars and is important for future landed assets and human exploration.

In addition to dust, MAVEN has observed that solar storms removed much of the atmosphere early in the planet’s history (two to three billion years ago). MAVEN has measured argon isotopes and current atmospheric escape rates to calculate that Mars lost at least half of its atmosphere early on due to intense solar storms; the loss of most of Mars’ atmosphere early on directly contributed to how long water was able to remain in liquid form on the surface.

In FY 2021, over 55 peer reviewed articles published used MAVEN data, some of the most pivotal, of which, was on the discrete aurora at Mars. and a special issue on how the Martian atmosphere responds to a Solar Minimum. This past year, MAVEN also created and began disseminating "space weather alerts"

OTHER MISSIONS AND DATA ANALYSIS

to the major stakeholders in the Mars Exploration Program. MAVEN is the only asset that can serve as a first warning system at Mars for major solar storms. MAVEN detects coronal mass ejections and high radiation streams that precede major solar storms and sends alerts to mission operators to safe Mars assets in advance of significant events.

As a Mars relay communication orbiter, MAVEN carries approximately 22 percent of the NASA Mars asset's data relay load. MAVEN set a new solar system record for throughput during a single communications session at another planet during a relay session with the Perseverance rover transferring a total of 2.34 Gbits and exceeding the prior record of 1.74 Gbits.

MARS SAMPLE RETURN

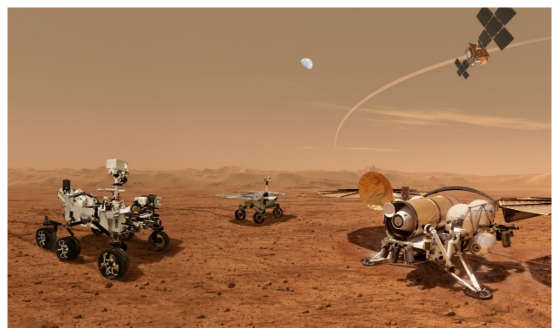
FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**241.6**	**653.2**	**822.3**	**800.0**	**700.0**	**600.0**	**612.1**
Change from FY 2022 Budget Request			**169.1**				
Percent change from FY 2022 Budget Request			**25.9%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The Mars Sample Return (MSR) Program will bring scientifically-selected samples from Mars to Earth to accomplish a solar system exploration goal that has been a priority since 1980 and included in the last two Planetary Decadal Surveys. The scientific driver of sample return is exploration of an ancient river-delta thought to present the best location for collecting samples that will reveal the early evolution of Mars, including the potential for life. MSR is a joint mission with the European Space Agency (ESA).



Retrieving Mars samples and returning them to Earth will expand our capability in space and significantly contribute to scientific knowledge. Back on Earth, the samples will be available to the world's best laboratories for intensive analysis to pursue answers to important science questions about planetary evolution including the potential for extraterrestrial life. Shown above is an artist rendition of MSR program elements.

The MSR Program consists of three coordinated flight-elements:

- Two Sample Retrieval Landers (SRLs); and
- The Earth Return Orbiter (ERO), launched by ESA.

The ERO will carry NASA's Capture, Containment, and Return System (CCRS), which includes the Earth Entry System (EES), and will launch as early as 2027. In 2028, the two SRLs will launch, one carrying the Mars Ascent Vehicle (MAV) and one carrying ESA's Sample Fetch Rover (SFR). Mars Rover 2020 is the first step in the sample return campaign and its Perseverance rover will continue to identify, sample, and cache samples on the Martian surface. The MSR Program will return the scientifically selected samples as early as 2033, making them available for analysis by the most advanced instrumentation on Earth.

The MSR program will deploy new capabilities developed through investments made by NASA and will leverage significant contributions from international partners. Sample return will advance human exploration of Mars by demonstrating the first round-trip to another planet and furthering our understanding of planetary protection challenges. Additionally, MSR's Sample Retrieval Landers (SRLs) will utilize advanced precision-landing technology, leveraging the Terrain Relative Navigation (TRN)

MARS SAMPLE RETURN

successfully used in the Mars Rover 2020 Perseverance landing. This technology applies directly to safely landing robotic precursors, human missions, and equipment near each other and in situ resources on the Martian surface.

EXPLANATION OF MAJOR CHANGES IN FY 2023

Detailed analysis of SRL landed mass requirements has led NASA to adopt a dual-lander architecture, with the second lander carrying the European-provided fetch rover. The development of a second lander necessitates a move to a 2028 launch date and 2033 sample return date and is consistent with the Mars Sample Return Independent Review Board's (IRB) finding that a dual-lander architecture may improve the probability of mission success.

Funding has been added to the mission's FY 2023 budget to reflect near-term second lander costs. NASA will update the FY 2024 and beyond funding levels in the next budget cycle to reflect cost growth due to the second lander and other costs for the Mars Sample Return mission.

The ESA ERO launch, with the CCRS payload, has moved from 2026 to 2027, also consistent with IRB recommendations.

ACHIEVEMENTS IN FY 2021

MSR completed the Agency Key Decision Point (KDP)-A milestone. Mars Rover 2020 Perseverance successfully took the first paired sample from the surface, as well as an atmospheric sample. The Earth Return Orbiter completed Preliminary Design Review (PDR) and the System Requirements Reviews (SRR) for the Capture, Containment, and Return, System (CCRS) and the Sample Fetch Rover (SFR).

The program agreed upon a common parts buy between Goddard Space Flight Center (GSFC) and the Jet Propulsion Laboratory (JPL) on the MSR CCRS element. The common buy includes over 3,500 piece parts across nine part types and four different manufacturers. Glenn Research Center (GRC) delivered prototype SFR wheels to ESA, per the NASA/ESA Memorandum of Understanding.

WORK IN PROGRESS IN FY 2022

With the maturation of the mission concept and finalization of the mission requirements, MSR is conducting a program-wide scheduling and costing exercise due to the need to adopt a dual-lander architecture, and in preparation for the Program System Readiness Reviews followed by the completion of the Program Key Decision Point-B gate review.

During FY 2022, the MSR team will complete the technology development, engineering prototyping, heritage hardware and software assessments, and other risk-mitigation activities identified in the project Formulation Agreement (FA) and during the start of the preliminary design phase.

MARS SAMPLE RETURN

KEY ACHIEVEMENTS PLANNED FOR FY 2023

The program will complete the preliminary design leading to a PDR and confirmation of the mission at KDP-C. At PDR, the mission will complete key technology development milestones, initiate major sub-system contracts, and continue critical long-lead procurements.

Program Elements

MARS SAMPLE RETURN (MSR)

MSR will consist of three separate launches, two NASA launches of the Sample Retrieval Lander carrying the Mars Ascent Vehicle (SRL-MAV), and the SRL-Sample Fetch Rover; and one ESA launch of the Earth Return Orbiter carrying the NASA CCRS. The goal of the program is to bring selected samples collected by Mars 2020 Perseverance to Earth.

The SRL-Sample Fetch Rover, carrying the ESA-provided Sample Fetch Rover, will rendezvous with the depot(s) of samples cached by the Mars 2020 Perseverance rover and return them to the Orbiting Sample (OS) container, a component of the SRL-MAV. The SRL-SFR launch readiness date is no earlier than 2028.

The SRL-MAV carries NASA's MAV and the Sample Transfer Arm (STA), which is part of the Sample Transfer System (STS). The STS, operated by NASA, will have the ability to retrieve the sample tubes from the Sample Fetch Rover and the Perseverance rover and place them into the orbiting sample container in the MAV. The MAV, launched from the SRL-MAV, is the first rocket that NASA will launch from the surface of another planet. It will launch the Orbiting Sample from Mars and place the Orbiting Sample in a stable orbit 400 km above the surface, where CCRS/Earth Return Orbiter will capture it. The MAV is a two-stage launch vehicle that utilizes two separate solid rocket motors for propulsion. Prior to its own launch from Mars, the MAV must survive Earth launch, a cruise phase to Mars, atmospheric entry and over 400 sols (Martian days), or 411 Earth days, of time on the Martian surface. The SRL-MAV launch readiness date is no earlier than 2028.

The third launch, the ESA Earth Return Orbiter carrying the CCRS, will capture and encapsulate the Orbiting Sample to "break the chain" of contact with the Martian material to satisfy planetary protection requirements and to ensure no risk to Earth's biosphere. The CCRS's Robotic Transfer Arm (RTA) will place the orbiting sample into the Earth Entry System (EES). The Earth Return Orbiter will deliver the EES to an Earth entry trajectory, and the EES will execute a ballistic entry and land at a selected U.S. landing site. The Earth Return Orbiter launch readiness date is no earlier than 2027.

Program Schedule

This estimated schedule is consistent with a 2028 SRL launch readiness date. All dates past the System Requirements Review are tentative pending further review.

MARS SAMPLE RETURN

Date	Significant Event
Apr 2022	System Requirements Review
Jun 2022	Key Decision Point-B
May 2023	Preliminary Design Review
Jul 2023	Key Decision Point-C
Apr 2024	Critical Design Review (CDR)
Nov 2025	Key Decision Point-D
Aug 2027	Earth Return Orbiter Launch
Jul 2028	Sample Retrieval Lander-MAV/STA Launch
Sep 2028	Sample Retrieval Lander-SFR Launch

Program Management & Commitments

The MSR Program Director at NASA Headquarters has overall responsibility for the MSR Program and reports directly to the Science Mission Directorate Associate Administrator. The Program Director is responsible for planning and implementing the program consistent with top-level policies, requirements, and funding. JPL is the lead Center for the MSR Program. The JPL MSR Program Manager is responsible for executing the program and reports to the SMD MSR Program Director.

The MSR System Engineering and Integration team (SE&I), which includes ESA membership, will oversee the development and control of Program requirements, planetary protection, and sample integrity. The MSR Program is responsible for sample integrity upon collection from the depot through landing on Earth and containment at the landing site. The MSR Program Office will also interface with the Mars Exploration Program during the Mars Rover 2020 Perseverance rover surface operation phase to coordinate depot caching. The future NASA Sample Receiving Project, funded in the Mars Exploration Program, will coordinate handoff of the samples upon their safe arrival on Earth.

Program Element	Provider
Sample Retrieval Lander (SRL-MAV/STA)	Provider: JPL Lead Center: JPL Performing Center(s): MSFC, LaRC, ARC, JPL Cost Share Partner(s): ESA
Sample Retrieval Lander (SRL-SFR)	Provider: TBD Lead Center: JPL Performing Center(s): GRC, JPL, ARC, LaRC Cost Share Partner(s): ESA

MARS SAMPLE RETURN

Program Element	Provider
Capture, Contain, and Return System (launched on Earth Return Orbiter)	Provider: GSFC Lead Center: GSFC Performing Center(s): JPL, LaRC, ARC Cost Share Partner(s): ESA

Acquisition Strategy

NASA conducted a delta-Acquisition Strategy Meeting (ASM) in May 2021 and updated center roles/responsibilities assignments (depicted in the previous table). NASA plans to award several competitive long-lead SRL and CCRS contracts.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
MAV Propulsion System	Northrop Grumman Systems Corp.	Elkton, MD
Aeroshell	Lockheed Martin	Denver, CO
Cruise Stage	Lockheed Martin	Denver, CO
MAV Integrated System	Lockheed Martin	Huntsville, AL

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	2022	Program SRR	TBD	PDR
Performance	SRB	2023	Program PDR	TBD	CDR
Performance	Program/Center	2023	CCRS CDR	TBD	SIR
Performance	Program/Center	2024	SRL CDR	TBD	SIR
Performance	SRB	2024	Program CDR	TBD	SIR
Performance	Program/Center	2025	CCRS SIR	TBD	ORR
Performance	SRB	2026	Program SIR	TBD	N/A
Performance	Program/Center	2026	SRL SIR	TBD	ORR
Performance	Program/Center	2027	CCRS ORR	TBD	N/A
Performance	Program/Center	2028	SRL ORR	TBD	N/A
Performance	SRB	2028	Program ORR	TBD	N/A

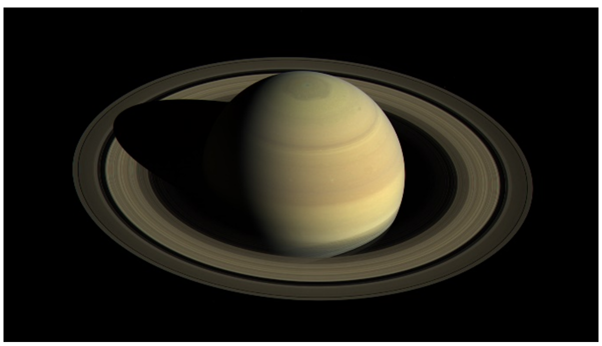
OUTER PLANETS AND OCEAN WORLDS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Jupiter Europa	434.8	472.1	**345.0**	303.3	101.2	80.6	77.7
Other Missions and Data Analysis	26.7	21.6	**11.8**	10.5	29.1	39.9	50.2
Total Budget	**461.5**	**493.7**	**356.8**	**313.8**	**130.3**	**120.5**	**127.9**
Change from FY 2022 Budget Request			**-136.9**				
Percent change from FY 2022 Budget Request			**-27.7%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



New analysis of Cassini observations of Saturn's rings has enabled measurements of Saturn's deep interior. Researchers used high-resolution images to measure the precise location and shape of narrow gaps within Saturn's rings (shown here). They related these features to vibrational resonances caused by Saturn's internal gravity structure, showing for the first time that the transition between rock and ice at Saturn's center, and metallic hydrogen further out, was a fuzzy edge, rather than a sharp transition. Credit: Christopher Mankovich and Jim Fuller (California Institute of Technology).

The Outer Planets and Ocean Worlds program enables the exploration of worlds in our solar system possessing vast expanses of liquid water. These liquid reservoirs provide insight into some of the most fundamental questions about life and the evolution of the solar system. The exploration of ocean worlds has high relevance and potential in the search for extant life and its habitable environments beyond Earth, one of NASA's strategic objectives.

NASA missions have revealed a surprising number of ocean worlds in our solar system while at the same time providing enticing, though limited, details about these unexpected oceans. Underneath its icy crust, Jupiter's moon Europa contains a global liquid water ocean holding twice as much water as all of Earth's oceans. Recent observations suggest active water plumes erupt from the surface of Europa. Scientists detected a similar, though smaller, global ocean on Enceladus, a small moon orbiting Saturn, which also emanates active plumes. Other moons (e.g., Ganymede, Titan, and perhaps Callisto) and possibly even Pluto also possess oceans deep beneath their surfaces. Unlike Europa and Enceladus, whose oceans have a rocky bottom; these oceans are sandwiched between ice layers. Titan also possesses huge lakes of liquid methane on its surface, the only place beyond Earth known to have lakes exposed to an atmosphere. Titan's lakes and atmosphere can reveal much about the exotic chemistry that ultimately led to life on Earth.

OUTER PLANETS AND OCEAN WORLDS

Astrobiology research, along with the exploration of Earth's oceans, has demonstrated the pervasiveness of life given the proper conditions and environment. Research and spacecraft measurements have increased our confidence that these ocean worlds possess at least some of the conditions necessary for extant life: long-lived oceans providing liquid water and a stable habitat, hydrothermal activity and other chemical sources providing energy, and the basic elements along with organics providing the necessary materials. In fact, Europa and Enceladus may possess all these conditions necessary for life. Thus, ocean worlds are the most likely places to search for currently habitable environments in the solar system and the life forms that could exist in those environments.

The Outer Planets and Ocean Worlds program enables science investigations spanning the diversity of worlds hosting large liquid bodies in the outer solar system. The unexpected discoveries of the first ocean worlds provided by large strategic missions, such as Galileo and Cassini, have enabled the definition of more focused scientific questions. These missions enable more focused scientific questions than smaller and less complex missions in the New Frontiers and Discovery programs can pursue.

EXPLANATION OF MAJOR CHANGES IN FY 2023

NASA has increased the total budget for the Europa Clipper mission by $703 million above the FY 2022 President's Budget Request phased from 2023 through 2034 as a result of the required project replan. The replan accommodated mission changes due to the launch vehicle procurement plan and cruise duration, COVID-19 impacts, assembly, test, and launch operations (ATLO) requirements, the updated schedule, and updated operations costs.

ESA has delayed the JUpiter ICy moons Explorer (JUICE) launch from 2022 until 2023. NASA has delivered instruments per the original schedule and is supporting spacecraft integration activities as needed.

This budget provides no funding to the Icy Satellites Surface Technology project, a congressionally-directed project focused on technology development for exploration of the icy moons of Jupiter and Saturn, in 2023. Researchers will still be able to compete for funding for this type of technology development from other planetary science programs.

NASA established a Decadal Future Mission budget line within the Outer Planets and Ocean Worlds program in anticipation of upcoming Planetary Science Decadal Survey results. This budget will provide NASA flexibility to respond to the recommendations of the report.

EUROPA CLIPPER

Formulation	Development	Operations

FY 2023 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027	BTC	Total
Formulation	1,219.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	1,219.0
Development/Implementation	941.9	434.8	472.1	**345.0**	303.3	11.9	0.0	0.0	0.0	2,509.0
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	89.3	80.6	77.7	1,024.5	1,272.0
2022 MPAR LCC Estimate	**2,160.9**	**434.8**	**472.1**	**345.0**	**303.3**	**101.2**	**80.6**	**77.7**	**1,024.5**	**5,000.0**
Total Budget	**2,160.9**	**434.8**	**472.1**	**345.0**	**303.3**	**101.2**	**80.6**	**77.7**	**1,024.5**	**5,000.0**
Change from FY 2022 Budget Request				**-127.1**						
Percent change from FY 2022 Budget Request				**-26.9%**						

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The 2022 MPAR LCC Estimate reflects the Fiscal Year 2022 Quarter 1 Financial Report, which is current as of December 2021. The requested budget authority is the project's current budget requirements which have seen programmatic changes approved by NASA since December 2021.

Flight hardware for the Europa Clipper mission is coming together at an increasing pace. Pictured above is the propulsion module containing the fuel tanks and engines. An additional module containing the electronics vault, the instruments, and the communications system will be placed atop this module, bringing the total height to more than 15 feet. With its solar arrays deployed, the spacecraft will span the length of a basketball court.

PROJECT PURPOSE

Jupiter's moon Europa has the largest known ocean in the solar system and is one of the most likely places to find life beyond our Earth. NASA developed concepts to explore Europa and determine if it is habitable based on characteristics of its vast oceans (twice the size of all the Earth's oceans combined); the ice surface-ocean interface; the chemical compositions of the intriguing, irregular brown surface areas; and the current geologic activity providing energy to the system.

NASA formulated the Europa Clipper mission in response to the planetary science Decadal Survey (Vision and Voyages for Planetary Science in the Decade 2013-2022), which identified a strategic mission

EUROPA CLIPPER

Formulation	Development	Operations

to Europa as the second-highest priority for planetary science flagship missions.

NASA's Europa Clipper spacecraft will conduct a detailed survey of Europa to determine whether the icy moon could harbor conditions suitable for life. The spacecraft, in orbit around Jupiter, will make 40 to 50 close passes over Europa, shifting its flight path for each flyby to soar over a different location so that it eventually scans nearly the entire moon.

After each flyby, the spacecraft will send its data back to Earth.

Because radiation trapped in Jupiter's magnetic field bathes Europa, Europa Clipper's electronics will be enclosed in a thick-walled vault, a technique successfully used for the first time by NASA's Juno spacecraft. The vault walls — made up of titanium and aluminum — will act as a radiation shield against most of the high-energy atomic particles, dramatically slowing down the aging effect that radiation has on the spacecraft's electronics.

EXPLANATION OF MAJOR CHANGES IN FY 2023

A project replan accommodated COVID-19 impacts, as well as assembly, test, and launch operations (ATLO) requirements, the updated schedule plan, and operations costs. NASA has increased the total budget for the Europa Clipper mission by $703 million above the FY 2022 President's Budget Request phased from 2023 through 2034 because of the required project replan.

PROJECT PARAMETERS

This mission will leverage the competitively selected payload of investigations to characterize the ice shell and any subsurface water, including their heterogeneity, ocean properties, and the nature of the surface-ice ocean exchange. It will also seek to understand the habitability of Europa's ocean through composition and chemistry of the surface and exosphere; understand the formation of surface features, including sites of recent or current activity; and identify and characterize high science interest locations. This will be the first NASA mission explicitly designed to explore an ocean world.

Europa Clipper's science payload consists of ten instruments grouped as follows:

- Cameras and spectrometers will create high-resolution images and composition maps of the moon's surface and thin atmosphere;
- An ice-penetrating radar, a magnetometer, plasma sensors, and a gravity investigation will reveal the moon's ocean and deep interior;
- The spacecraft's thermal camera will pinpoint warmer ice and might reveal recent eruptions of water or bodies of liquid water buried near the surface; and

EUROPA CLIPPER

Formulation	Development	Operations

- A dust analyzer and a mass spectrometer will study the chemistry of particles and gases ejected from the surface and subsurface of the moon.

Europa Clipper will launch on a SpaceX Falcon Heavy launch vehicle, utilizing a Mars-Earth Gravity Assist (MEGA) trajectory in October 2024. The Europa Clipper mission will spend four years in orbit around Jupiter, conducting its scientific observations by completing approximately 44 close fly-bys of Europa.

ACHIEVEMENTS IN FY 2021

During FY 2021, the Europa Clipper project finalized the system design. Every major subsystem and each instrument underwent a Critical Design Review (CDR), demonstrating progress to independent boards. The project completed the full project CDR in December 2020. Flight hardware fabrication began, with several mission instruments moving into final fabrication by the end of FY 2021 in preparation for the start of ATLO in mid-FY 2022. NASA completed the launch vehicle procurement, consistent with the FY 2021 Consolidated Appropriations Act (P.L.160-260), and selected a SpaceX Falcon Heavy to launch Europa Clipper. Once the mission-unique requirements of the selected launch vehicle became known, NASA began a replan of the mission schedule, technical, and budget baseline. This replan will accommodate COVID-19 impacts, as well as ATLO requirements and updated operations costs.

WORK IN PROGRESS IN FY 2022

The project completed its System Integration Review (SIR) in November 2021. NASA will conduct the Key Decision Point-D (KDP-D) review and finalize the project replan in the second quarter of FY 2022. The spacecraft will enter the ATLO phase in the spring of 2022 and final flight hardware delivery will continue to the Jet Propulsion Laboratory (JPL) for integration.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

The project will continue integration and test of flight hardware into the final configuration as the ATLO process continues during Phase D.

EUROPA CLIPPER

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

At confirmation, the project established a Launch Readiness Date (LRD) of September 2025 to fully accommodate all possible launch vehicles available to the mission. NASA selected the SpaceX Falcon Heavy launch vehicle for Europa Clipper in FY 2021 and established a target LRD of October 2024.

Milestone	Confirmation Baseline Date	FY 2023 PB Request
KDP-C	Aug 2019	Aug 2019
CDR	May 2020	Dec 2020
SIR	Mar 2021	Nov 2021
KDP-D	Apr 2021	Mar 2022
ORR	May 2023	July 2024
Launch Readiness Date	Sep 2025	Oct 2024
Phase E Start	Nov 2025	Nov 2024

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2020	2,412.8	69%	2022	2,509.0	4.0	LRD	Sep 2025	Oct 2024	-11

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

EUROPA CLIPPER

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**2,412.8**	**2,509.0**	**+96.2**
Aircraft/Spacecraft	818.7	1,008.2	+189.5
Payloads	168.7	388.7	+220.0
Systems I&T	63.2	56.3	-6.9
Launch Vehicle	432.0	202.0	-230.0
Ground Systems	104.8	145.7	+40.9
Science/Technology	24.8	33.4	+8.6
Other Direct Project Costs	800.6	674.5	-126.1

Project Management & Commitments

The Jet Propulsion Laboratory is responsible for project management.

Element	Description	Provider Details	Change from Baseline
Spacecraft	Spacecraft Bus with all flight subsystem capabilities	Provider: JPL Lead Center: JPL Performing Center(s): JPL, APL, GSFC, MSFC, JSC, KSC Cost Share Partner(s): N/A	N/A
Launch Vehicle	Falcon Heavy rocket	Provider: SpaceX Lead Center: KSC Performing Center(s): KSC Cost Share Partner(s): N/A	Previously Space Launch System (SLS)
Europa Ultraviolet Spectrograph (UVS) Instrument	Ultraviolet Spectrograph	Provider: SwRI Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

EUROPA CLIPPER

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
MAss SPectrometer for Planetary EXploration/Europa (MASPEX)	Time-of-Flight Mass Spectrometer	Provider: SwRI Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Europa Imaging System (EIS)	Narrow angle and wide-angle cameras	Provider: APL Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
SUrface Dust Analyzer (SUDA)	Dust Analyzer; Mass Spectrometer	Provider: LASP - CU Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Europa Thermal Emission Imaging System (E-THEMIS)	Thermal Imager	Provider: ASU Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Interior Characterization of Europa Using Magnetometry (ICEMAG)	Magnetometer	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	Terminated
Europa Clipper Magnetometer (ECM)	Magnetometer	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	Facility instrument to replace ICEMAG functionality
Plasma Instrument for Magnetic Sounding (PIMS)	Plasma Instrument - Faraday Cups	Provider: APL Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Mapping Imaging Spectrometer for Europa (MISE)	Infrared Spectrometer	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A

EUROPA CLIPPER

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON)	Sounding Radar	Provider: Univ. of Texas Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: COVID-19 mitigations further slow the progress at delivering organizations and / or subcontractors, or continue substantially beyond the accommodations currently planned, Then: Further delays in hardware deliveries to ATLO will occur, resulting in delays in ATLO progress and potentially an impact to Clipper's LRD.	Estimated hardware delivery dates incorporating COVID-19 impacts have been updated and will be incorporated into the replan. The project is tracking progress against plans adjusted for current COVID-19 impact estimates and evaluating for changes in impact profiles which would affect the resources needed for mitigation.
If: Solar Array manufacturing and development continues to experience issues, Then: Solar Arrays will not be delivered per the baseline schedule, resulting in a threat to the launch date.	The project formed a committee to assess status and resolve schedule threat issues. Flight System management and Solar Array team members meet weekly to review top threat details and move to resolution. Airbus manages technical and programmatic threats to development and delivery schedule and reports status regularly. The project is conducting a Solar Array Risk Trade Study to determine priority and risk of activities required at JPL if the arrays arrive at JPL first, versus delivery straight to KSC, and the required delivery schedule associated with each option.

Acquisition Strategy

The Europa Clipper spacecraft is a JPL "in-house" build with each subsystem completing an internal make/buy assessment, with competed industry contracts where appropriate. JPL is collaborating with the Applied Physics Laboratory (APL) for development, leveraging each other's strengths as well as those of other NASA centers. As a result, APL is responsible for the propulsion module and the telecom subsystem, and GSFC will provide the propulsion subsystem. The Europa Clipper payload is comprised of nine investigations, each competitively selected via a Science Mission Directorate Announcement of Opportunity.

EUROPA CLIPPER

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Telecom and Propulsion Subsystems	APL	Laurel, MD
EIS instrument	APL	Laurel, MD
PIMS instrument	APL	Laurel, MD
REASON instrument	University of Texas University of Iowa	Austin, TX Iowa City, IA
MISE instrument	APL	Laurel, MD
SUDA instrument	LASP - University of Colorado	Boulder, CO
MASPEX instrument	SWRI	San Antonio, TX
UVS instrument	SWRI	San Antonio, TX
E-THEMIS instrument	ASU Ball Aerospace Raytheon Vision Systems	Tempe, AZ Boulder, CO Goleta, CA
Solar arrays	Airbus Defence and Space	Leiden, The Netherlands Ottobrun, Germany
Launch vehicle	SpaceX	Hawthorne, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Jan 2017	Europa SRR and MDR	Successful	PDR
Performance	SRB	Aug 2018	PDR	Successful	Delta-PDR
Performance	SRB	Jun 2019	Delta-PDR	Successful	CDR
Performance	SRB	Dec 2020	CDR	Successful	SIR
Performance	SRB	Nov 2021	SIR	Successful	ORR
Performance	SRB	May 2024	ORR	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Planetary Decadal Future	0.0	0.0	**0.0**	0.0	18.5	29.3	39.6
Icy Satellites Surface Technology	14.2	10.0	**0.0**	0.0	0.0	0.0	0.0
JUICE - Jupiter Icy Moons Explorer	4.4	1.1	**2.4**	0.8	0.8	0.8	0.8
Outer Planets Research	8.1	10.5	**9.3**	9.8	9.8	9.8	9.8
Total Budget	**26.7**	**21.6**	**11.8**	**10.5**	**29.1**	**39.9**	**50.2**
Change from FY 2022 Budget Request			**-9.8**				
Percent change from FY 2022 Budget Request			**-45.4%**				

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Other Missions and Data Analysis includes NASA's contribution to the European Space Agency (ESA) JUpiter ICy Moons Explorer (JUICE) mission and Outer Planets Research.

Mission Planning and Other Projects

JUPITER ICY MOONS EXPLORER (JUICE)

NASA is collaborating on this ESA-led mission to Ganymede and the Jupiter system. Together the Europa Clipper and JUICE missions provide an opportunity for comparative investigation of three of the ocean worlds in the Jupiter system: Europa, Ganymede, and Callisto. Researchers believe all three worlds possess liquid water oceans at varying depths beneath their surfaces. ESA plans to launch the mission in 2023 for arrival at Jupiter as early as 2030. The NASA contribution consists of three separate pieces of hardware: one full instrument, the Ultra Violet Spectrograph (UVS); two sensors for the Swedish National Space Agency Particle Environment Package suite of instruments (PEP-Hi); and the transmitter and receiver hardware for the Radar for Icy Moons Exploration (RIME) instrument.

Recent Achievements

NASA instrument teams continue to support ESA-led integration activities at Airbus. The NASA-funded PEP team delivered two instruments (JENI and JoEE) for spacecraft integration, the RIME team is working to resolve unexpected noise generated by another instrument that could interfere with data acquisition and the UVS team is supporting advanced operational testing now that it is integrated onto the spacecraft.

OTHER MISSIONS AND DATA ANALYSIS

OUTER PLANETS RESEARCH

Outer Planets Research increases the scientific return of current and past NASA outer planets missions and paves the way for future missions (e.g., refining landing sites on Titan, characterizing the ice shell on Europa and Enceladus).

Recent Achievements

New research on Enceladus investigated the relationship among its heat flux, ice shell thickness, and the pressure within the ocean. As the heat flux (the amount of heat emitted by the interior) decreases, the ice shell thickness increases, which in turn increases the pressure within the ocean. The pressurization of the ocean can also affect surface features and contribute to the jets emanating from the south pole. Ocean pressurization also affects the potential habitability of the ocean.

PLANETARY DECADAL FUTURE

NASA expects the release of the new Planetary Science and Astrobiology Decadal Survey in the Spring of 2022. This budget request includes funding in future years to begin mission formulation studies and early technology development associated with Decadal Survey recommendations. The inclusion of the budget for this effort under Outer Planets and Ocean Worlds does not indicate a NASA preference for or prediction of the priorities of this upcoming Decadal Survey.

RADIOISOTOPE POWER

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**146.3**	**148.6**	**166.3**	**189.7**	**212.1**	**199.2**	**171.0**
Change from FY 2022 Budget Request			**17.7**				
Percent change from FY 2022 Budget Request			**11.9%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Shown above is the Sunpower Robust Stirling Convertor testing at the NASA Glenn Research Center's Stirling Research Laboratory, a possible power conversion solution for the Dynamic Radioisotope Power System, which will enable future missions to use much less Pu-238 to produce the same amount of power.

Planetary Science missions demand advances in technology to enable successful trips to distant solar system destinations with harsh environments, and to enable missions with highly challenging trajectories and operations. To meet these needs, Planetary Science supports the development of advanced multi-mission capabilities through technology investments in key spacecraft systems, such as radioisotope power. The Radioisotope Power Systems (RPS) Program includes technology maturation and system development and works in partnership with the U.S. Department of Energy (DOE) to ensure continuing plutonium-238 (Pu-238) production and operations infrastructure. The program also supports nuclear launch approval activities.

EXPLANATION OF MAJOR CHANGES IN FY 2023

This budget supports needed infrastructure investments and an increase to the RPS constant rate production of continuing plutonium-238, which maintains the RPS capability at the Department of Energy (DOE). It also adds funding for the General Purpose Heat Source - Radioisotope Thermoelectric Generator (GPHS-RTG, Cassini-type) proto-flight development to support missions in the 2030s timeframe.

ACHIEVEMENTS IN FY 2021

Industry teams delivered two of the three Dynamic Radioisotope Power System (DRPS) technology demonstration convertors and performance data made possible by advancements in energy conversion technologies. These efforts will culminate in a DRPS activity technology maturity review in FY 2022. NASA initiated a DRPS design effort, supported by DOE, for a potential lunar surface RPS solution,

RADIOISOTOPE POWER

which could provide longer lasting power for scientific exploration. DOE plans to award a contract in early FY 2022.

The next generation RTG technology effort down-selected to a single contractor and initiated refurbishment of an existing GPHS-RTG system along with initiating development of a production line needed to deliver a Next-Gen Mod 1. The team expects this new system to have comparable performance to prior GPHS-RTG systems used on Cassini and New Horizons.

NASA continued to develop processes and decision-making steps applicable to RPS usage on NASA missions by developing a Radioisotope Heater Unit (RHU). DOE developed a documented safety analysis for the RHU. DOE also initiated development of a documented safety analysis for the General Purpose Heat Source (GPHS) module, the building block for fueling an RPS.

The NASA RPS team coordinated with DOE to provide a Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) to support the Dragonfly mission launch in 2027. Dragonfly is funding the MMRTG flight unit.

WORK IN PROGRESS IN FY 2022

NASA will continue to support the utilization of RPS on missions, serve as a liaison between DOE and the Dragonfly mission on system integration, and provide services to enable the baselined MMRTG. NASA will acquire, via DOE, existing and emerging RPS generators.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

NASA will evaluate if an initial unit of the Next-Gen RTG (Mod 0), based on the GPHS-RTG existing hardware, is flight ready for a future mission. DOE and NASA will continue to work on development of a Dynamic Radioisotope Power System targeting a lunar mission that will operate through the lunar night, with a PDR-level design and a brassboard-level assembly in 2023.

Program Elements

RADIOISOTOPE POWER SYSTEM (RPS)

The RPS project will continue to ensure the availability of RPS for the exploration of the solar system in environments where conventional solar or chemical power generation is impractical or impossible. NASA will achieve this goal by working with DOE to provide fueled RPS to missions and to support mission design and integration activities. The program will continue to reduce costs to the missions and increase system performance. RPS will continue energy conversion research and development to advance state-of-the-art performance in heat to electrical energy conversion.

DOE OPERATIONS AND ANALYSIS

NASA funds the DOE national laboratory personnel and infrastructure required to maintain the capability to develop and fuel radioisotope power systems for deep space missions. DOE resumed domestic

RADIOISOTOPE POWER

production of Pu-238 for the first time since the 1980s. They are now using a constant rate production approach. NASA funds the effort and the DOE Oak Ridge National Laboratory leads the effort and irradiates targets at its High Flux Isotope Reactor. The DOE Idaho National Laboratory (INL) supplies Neptunium-237 and irradiates targets at the Advanced Test Reactor, required to meet Pu-238 production rates. DOE continues to increase annual production, producing approximately 400 grams per year. Over the next several years, refining and automating the process will help ramp production up to a full operational capability of 1.5 kilograms per year by 2026. DOE Los Alamos National Laboratory (LANL) manages the existing Pu-238 inventories and manufactures fuel, resulting in continual annual fueled clad manufacturing by LANL and delivery to INL at a CRP rate of 10 to 15 clads per year. INL integrates the fueled clads with generator systems and manages the transportation and launch operations activities in support of NASA missions.

Program Management & Commitments

Glenn Research Center (GRC) manages the Radioisotope Power Systems (RPS) Program.

Program Element	Provider
RPS	Provider: GRC Lead Center: GRC Performing Center(s): GRC, JPL, GSFC, KSC, DOE Cost Share Partner(s): N/A
DOE Operations and Analysis	Provider: DOE Lead Center: GRC Performing Center(s): GRC Cost Share Partner(s): N/A

Acquisition Strategy

DOE provides radioisotope power systems and production operations on a reimbursable basis. Maturity of the technologies determines the timeline for the acquisition of technologies and new systems. NASA or DOE laboratory-competed acquisitions help mature technology before system development begins. NASA-led DOE laboratory acquisitions procure unfueled designs and flight-qualified hardware when initiating a system development.

The program acquires content via existing Agency contracts with JPL and APL. The program will use in-house or competitive procurements as needed.

ASTROPHYSICS

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Astrophysics Research	249.3	280.3	**329.8**	350.8	345.5	348.4	350.1
Cosmic Origins	618.5	318.9	**298.5**	316.5	316.3	316.6	316.6
Physics of the Cosmos	146.4	165.8	**159.9**	188.1	182.4	182.2	177.6
Exoplanet Exploration	552.4	544.7	**522.2**	450.2	423.0	388.4	258.0
Astrophysics Explorer	204.4	265.5	**245.6**	291.4	311.3	385.0	523.2
Total Budget	**1,770.9**	**1,575.2**	**1,556.0**	**1,597.0**	**1,578.5**	**1,620.5**	**1,625.6**

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Astrophysics

ASTROPHYSICS RESEARCH

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Astrophysics Research and Analysis	91.1	107.4	**111.0**	113.0	114.1	115.2	116.4
Balloon Project	44.8	45.8	**45.7**	46.3	46.3	46.3	46.3
Science Activation	45.6	55.6	**55.6**	55.6	55.6	55.6	55.6
Other Missions and Data Analysis	67.8	71.5	**117.6**	135.9	129.5	131.2	131.9
Total Budget	**249.3**	**280.3**	**329.8**	**350.8**	**345.5**	**348.4**	**350.1**
Change from FY 2022 Budget Request			**49.5**				
Percent change from FY 2022 Budget Request			**17.7%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The JPL-SLS instrument is a passive submillimeter wave radiometer measuring gases in Earth's stratosphere such as ozone, ClO, BrO and HO2. This photo reflects the launch configuration with the Balloon Program Office Mobile Launch Vehicle "Big Bill." -Credit NASA 28 Aug 21.

The Astrophysics Research program studies a wide range of astronomical observations from the births of the first stars, black holes, and distant galaxies in the cosmic history, to the nature of planets orbiting other stars in our Milky Way galaxy. High-altitude balloon and sounding rocket flights are used to test new types of instruments which study the nature of energetic particles.

The program provides basic research awards for scientists to test their theories and to understand how they can best use data from NASA missions to gain new knowledge from the universe. Awardees analyze the data from Astrophysics missions to understand astronomical events, such as the explosion of a star, or the fingerprints of early cosmic history in the microwave background. Competitively-awarded science investigations in Astrophysics Research can also include funding for data analysis and techniques, theory and computation, laboratory astrophysics, and capital equipment purchases. The program also develops innovative technologies for future missions, including detectors and electronics, optics, gratings, and coatings.

ASTROPHYSICS RESEARCH

EXPLANATION OF MAJOR CHANGES IN FY 2023

Increased funding within Research & Analysis (R&A) will continue investments in a data initiative coordinated within SMD, the High Altitude Student Platform (HASP) dedicated for training future scientists and engineers, and the SMD Bridge program element that will strengthen partnerships with Minority Serving Institutions with a goal of broadening participation in NASA's science research programs.

Increased funding in the research program supports the recommendations of the 2020 Decadal Survey "Pathways to Discovery in Astronomy and Astrophysics for the 2020s" to augment selected R&A program elements.

This budget request supports the Senior Review project. There is no impact to science or operations.

ACHIEVEMENTS IN FY 2021

In FY 2021, NASA evaluated 1,064 proposals submitted to the Astrophysics Research program using subject-matter experts as peer reviewers and made diverse selections for investigators, institution types and geography over a broad range of science investigations. Over half of all Principal Investigators (PIs) are new PIs who have not been previously funded by the research programs. In addition, NASA evaluated 2,507 proposals submitted to the General Observer and Guest Investigator programs of NASA's eight currently operating Astrophysics missions and provided funding to the broad scientific community for new observations, archival, and theory investigations.

On September 27, 2021, NASA launched its second Astrophysics CubeSat mission, the Colorado Ultraviolet Transit Experiment (CUTE) as a ride share with Landsat-9. After deployment on September 28, 2021, CUTE opened its solar arrays and successfully received commands from the ground by the University of Colorado Boulder. CUTE will take multiple medium resolution UV spectra of hot Jupiters during transit around stars to measure the composition of the atmosphere being ablated, removed by vaporization or eroded away.

In FY 2021, NASA launched two Astrophysics sounding rocket payloads. The Dual-channel Extreme Ultraviolet Continuum Experiment (DEUCE) is testing if B-Stars are viable candidates for providing the ionizing radiation to the intergalactic medium. The Cosmic Infrared Background Experiment (CIBER-2) is measuring the cosmic near-infrared extragalactic background light.

NASA conducted two balloon campaigns in FY 2021 and successfully launched ten balloons during the spring (April - June) and fall (August - October) Fort Sumner, New Mexico campaigns. The Antarctica Long-Duration and the Wanaka, New Zealand Super-Pressure balloon campaigns were canceled due to COVID-19 concerns and restrictions.

Several NASA-funded projects have been developing new types of optics for the far-infrared and millimeter using superior optical material (such as silicon) and state of the art metamaterial surface structures. By developing a silicon gradient index lens (i.e., a flat, planar lens without curved surfaces with a metamaterial surface to reduce reflective light losses), engineers can fabricate a nearly ideal lens. Researchers have provided the first successful demonstration of this planar lens that focuses just like a traditional lens with reduced light loss relative to that seen for a standard lens.

The recently selected Compton Spectrometer and Imager (COSI) mission will explore the extreme environments of the gamma-ray universe using germanium strip detectors. COSI requires an Application

ASTROPHYSICS RESEARCH

Specific Integrated Circuit (ASIC) to instrument these detectors while meeting size, mass, and power requirements. With funding from the Astrophysics Research program, a team of researchers at the Naval Research Laboratory has successfully developed an ASIC that meets the stringent energy and timing requirements of COSI.

Current models suggest that almost half the normal matter in the universe exists in the form of diffuse gas at temperatures near one million degrees and above. Much of this material has never been found but is thought to be divided between an intergalactic “web” of matter collected around dark matter filaments and a “circumgalactic medium” surrounding individual galaxies. Learning the nature of this circumgalactic medium is essential to understanding the evolution of galaxies and following cosmological structure formation down to the scale of individual galaxies and groups. X-ray microcalorimeter detectors, such as those planned to launch on XRISM and Athena, have the required energy resolution but lack the required sensitivity to detect these faint extended sources. With funding from the Astrophysics Research program, researchers are developing pixels 16 times larger than those on Athena that can still achieve the required energy resolution. The project includes building a suborbital sounding rocket instrument that will use a smaller number of these pixels to investigate the million-degree bubble of hot gas in which the Sun is embedded, and similar material in the disk of our Galaxy.

Researchers discovered a new type of supernova, 2018zd, using Hubble and Spitzer data, which has shown strong evidence of being triggered by “electron capture,” which scientists suspect to occur for stars between eight and 10 times the mass of the Sun. These stars are too massive to expire as white dwarf stars, but too small to undergo standard core-collapse supernova explosions. This discovery will provide scientists with a deeper understanding of the diversity of stellar death.

Supercomputer simulations of planet formation show how gas disks help planets move in ‘lock-step’ resonant orbits – thereby explaining observations from NASA’s Kepler mission showing a high rate of exoplanet systems with multiple planets all orbiting in resonances. These simulations show how a gas disk can shepherd planets into more circular orbits, where they lock into resonances; this early nudge by gas into stable orbits may protect new planets from giant impacts, eccentricity excitation, and chaos that would otherwise dislodge the planets from their orbit. Showing how exoplanet orbits can remain stable is a step toward understanding the longevity of planetary systems.

Goddard Space Flight Center is developing Active Pixel Sensors (APSs) for future space-based gamma-ray telescopes. The novel sensor utilizes Complementary-Metal-Oxide Semiconductor (CMOS) processes. Cell phones and other consumer electronics extensively use CMOS processes. Prototype detectors developed under this program showed an order of magnitude improvement over the current state-of-the-art that enhances and enables high-energy studies of the extreme universe.

The Science Activation project, which comprises four dozen teams of which half focus on underrepresented learners and communities, generated 23 million learner interactions in more than 110 countries (22 million in the United States), held 55,550 volunteer events since the program began (2,500 during the pandemic), leveraged 268 partnerships within the collaborative network, published 81 formal publications capturing evidence-based approaches, provided 350 science centers and museums with hands-on toolkits that were also available digitally in both English and Spanish to all users, and supported more than 421 subject matter experts in interactions with learners across the five science disciplines.

ASTROPHYSICS RESEARCH

WORK IN PROGRESS IN FY 2022

New initiatives starting in FY 2022 include the implementation of recommendations of the Astro2020 Decadal Survey “Pathways to Discovery in Astronomy and Astrophysics for the 2020s” in areas of faculty diversity and early career faculty awards, workforce development and diversity, student traineeship programs, and independent postdoctoral fellowship programs, as well as an external review of NASA’s balloon program for optimal balance.

NASA scheduled six Astrophysics sounding rockets for launch in FY 2022. The first and the third mission will launch from the White Sands Missile Range and the second will launch from Wallops Island. The last three missions are part of the Astrophysics Australia Launch campaign. The first sounding rocket is Suborbital Imaging Spectrograph for Transition region Irradiance from Nearby Exoplanet (SISTINE-2) to study the ultraviolet radiation environment around low-mass stars and the effects of that UV on potential exoplanet atmospheres. NASA will conduct the Australia Sounding Rocket Campaign on a commercial range near Arnhem, in Australia's Northern Territory. The campaign consists of three Astrophysics missions: X-ray Quantum Calorimeter (XQC), SISTINE, and the Dual-channel Extreme Ultraviolet Continuum Experiment (DEUCE).

NASA is planning three balloon campaigns in FY 2022 including a Spring 2022 New Zealand Super Pressure Balloon campaign, a Sweden campaign with multiple science and engineering flights, and a Fall Fort Sumner campaign with multiple science, engineering, and student flights.

Astrophysics has three more CubeSats in development: BurstCube, to detect sudden gamma-ray bursts that occur when neutron stars collide; Supernova Remnants and Proxies for ReIonization Testbed Experiment (SPRITE) to observe UV spectra of star forming regions in numerous nearby galaxies and to trace the history of star formation; and BlackCat, to discover transient X-ray sources.

The Science Activation project is expanding its expert base and connections into the Nation's communities for learners of all ages, not just students. Work is continuing to fill gaps identified in the 2019 National Academies of Sciences, Engineering, and Medicine (NASEM) assessment, including intensive and valuable work with the portfolio evaluation team, which has helped to develop a graphical logic model that serves as a framework for ongoing improvement. The project is meeting stakeholder priorities in the areas of rural learners, underserved communities, and emergent multilingual learners, as well as for place-based learning.

Science Activation continues to support competitive selections that broaden participation for learners in new and augmented collaborations for rural, indigenous, and other underserved areas and plans to use lessons learned from past celestial and other milestone events to engage these communities.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

NASA will initiate R&A augmentations recommended in the 2020 Decadal Survey "Pathways to Discovery in Astronomy and Astrophysics for the 2020s."

NASA will continue a competed Astrophysics Research program with emphasis on detector, instrument, optics, and key supporting technologies for use as payloads in future missions. Theoretical work will provide the foundation to develop science requirements for new missions. Data analysis will multiply the science yield from NASA’s Astrophysics missions. NASA will initiate the next cohort of Theoretical and Computational Astrophysics Network (TCAN) investigations.

ASTROPHYSICS RESEARCH

The Balloon project plans to support a super-pressure balloon campaign from New Zealand, and two domestic campaigns with conventional flights from Palestine, Texas, and Fort Sumner, New Mexico (spring and fall).

Within Science Activation, planning for upcoming U.S. solar eclipses in 2023 and 2024 is underway. Science Activation had three eclipse-focused teams start up in January 2022, from ROSES-21 selections: Eclipse Ambassadors Prepare Communities Off the Path for Two Solar Eclipses – from Astronomical Society of the Pacific, Nationwide Eclipse Ballooning Project 2022-2025 – from Montana Space Grant, and a Heliophysics Education and Eclipse Framework by NASA HEAT – from NASA GSFC (continuing, but reframed, project). These three teams will lead Science Activation in a collective effort to maximize the learning potential from both the 2023 and 2024 eclipses. Science Activation is also connecting with the Transform to Open Science (TOPS) initiative from the SMD Science Data Office to extend its impact to all learners to the maximum extent possible through our collaborative network.

Program Elements

RESEARCH AND ANALYSIS

This project supports basic research, solicited through NASA's annual Research Opportunities in Space and Earth Sciences (ROSES) announcements. NASA solicits investigations relevant to Astrophysics over the entire range of photon energies, gravitational waves, and particles of cosmic origin. Scientists and technologists from a mix of disciplines review proposals and provide findings that underlie NASA's merit-based selections.

This project also solicits technology development for detectors and instruments for potential use on future space flight missions, and science and technology investigations using sounding rockets, high-altitude balloons, and similar platforms. A new type of scientific instrument often flies first on a stratospheric balloon mission or on a sounding rocket flight, which takes it briefly outside Earth's atmosphere. Instruments for balloons and sounding rockets are less expensive than orbital missions and experimenters can build them quickly to respond to unexpected opportunities, such as a newly discovered supernova. The experimenter usually retrieves the equipment after the flight so that they can test, improve, and fly the new instruments again. Suborbital flights are important for training the next generation of scientists and engineers to maintain U.S. leadership in science, technology, engineering, and math. The project also supports small experiments flown on the International Space Station, laboratory astrophysics, and limited ground-based observations.

The Astrophysics Theory element solicits basic theory investigations needed to interpret data from NASA's space astrophysics missions and develops the scientific basis for future missions. Astrophysics Theory topics include the formation of stars and planets, supernova explosions and gamma-ray bursts, the birth of galaxies, dark matter, dark energy, and the cosmic microwave background.

The Exoplanet Research element solicits observations to detect and characterize planets around other stars and to understand their origins.

The Nancy Grace Roman Technology Fellowship develops early career researchers, who could lead future flight instruments and missions. Initially, NASA identifies promising early career researchers and supports their investigations. NASA then selects a subset of fellows for additional funding to start a laboratory or develop a research group at the Fellow's institution.

ASTROPHYSICS RESEARCH

The SMD Bridge program element is a new initiative designed to boost diversity, equity, inclusion, and accessibility within the NASA workforce and within the U.S. science and engineering community. Included as part of the FY 2022 President's Budget, the SMD Bridge program element will increase engagement and partnering between Minority-Serving Institutions, other PhD-granting universities, and NASA centers with a focus on paid research and engineering studentships at participating institutions to transition science and engineering students from undergraduate studies into graduate schools and employment by NASA. SMD will be facilitating one or more community planning workshops to collaboratively create the Bridge program element with all stakeholders.

BALLOON PROJECT

The Balloon project offers inexpensive, high-altitude flight opportunities for scientists to conduct research and test new technologies before space flight application. Balloon experiments cover a wide range of disciplines in astrophysics, solar physics, heliospheric physics, and Earth upper-atmosphere chemistry as well as selected planetary science, such as comet observations. Observations from balloons have detected echoes of the Big Bang and probed the earliest galaxies. The Balloon project continues to increase balloon size and enhance capabilities, including an accurate pointing system to allow high-quality astronomical imaging and a super-pressure balloon that maintains the balloon's integrity at a high altitude to allow much longer flights at mid-latitudes that include nighttime viewing of astronomical objects.

SCIENCE ACTIVATION

The Science Activation project delivers SMD's unique content and expertise into the learning environment for learners of all ages. Through 2025, a cooperative network of 43 competitively-selected teams from across the nation will connect NASA science experts, real content, and experiences with community leaders to conduct science in ways that activate minds and promote deeper understanding of our world and beyond. Awardees of cooperative agreements work collaboratively with each other, with internal NASA organizations, and with local and national partners to achieve a multiplier effect utilizing NASA investments. They focus on building stronger connections with subject matter experts and broadening participation by underserved audiences. All awards include independent evaluators that assess the individual project's measures of success as well as a portfolio-level independent evaluator.

Science Activation plans better connections between subject matter experts in both strategic and competed arenas and the community-based networks in all 50 states and territories. Funding will provide opportunities for indigenous learners in the Southwest, Appalachia, upper Northwest, and Alaska. Neurodiverse high school students will have new opportunities as will low-vision and bilingual language learners in communities across the United States. New processes will ensure cohesion across the collective set of awards and stronger linkage between objectives and measures of success using agreed upon mid-level objectives. In addition, NASA will support, connect, and report two dozen citizen science activities for life-long learners.

In 2021, NASA realigned the Science Activation project with stakeholder, community, and NASEM feedback. In FY 2022, new processes will ensure cohesion across the collective set of over 50 awards and stronger linkage between objectives and measures of success using agreed upon mid-level objectives. In addition, NASA will highlight and report new citizen science efforts beyond the current 25 projects. Over one-third of the Science Activation portfolio focuses on broadening participation among underrepresented communities, including Native American nations, undergraduate students participating from Historically

Black Colleges and Universities; learners on the autism spectrum; people who are blind or have low vision; and community college students.

Program Schedule

The program issues solicitations every year. A Senior Review process assesses all missions in the extended operations phase every three years and all data archives every three or four years.

Date	Significant Event
Q1 FY 2022	ROSES-2021 selection within six to nine months of receipt of proposals
Feb 2022	ROSES-2022 NRA solicitation release
Mar 2022	Senior Review of Operating Missions
Q1 FY 2023	ROSES-2022 selection within six to nine months of receipt of proposals
Feb 2023	ROSES-2023 NRA solicitation release
Q1 FY 2024	ROSES-2023 selection within six to nine months of receipt of proposals
Feb 2024	ROSES-2024 NRA solicitation release
Mar 2024	Astrophysics Archives Programmatic Review
Q1 FY 2025	ROSES-2024 selection within six to nine months of receipt of proposals
Feb 2025	ROSES-2025 NRA solicitation release
Mar 2025	Senior Review of Operating Missions
Q1 FY 2026	ROSES-2025 selection within six to nine months of receipt of proposals
Feb 2026	ROSES-2026 NRA solicitation release

Program Management & Commitments

Program Element	Provider
Research and Analysis Project	Provider: All NASA Centers Lead Center: Headquarters (HQ) Performing Center(s): All Cost Share Partner(s): None
Balloon Project	Provider: Wallops Flight Facility (WFF) Lead Center: WFF Performing Center(s): WFF Cost Share Partner(s): None

ASTROPHYSICS RESEARCH

Program Element	Provider
Science Activation	Provider: All NASA Centers Lead Center: Headquarters (HQ) Performing Center(s): All Cost Share Partner(s): OSTEM

Acquisition Strategy

NASA issues solicitations for competed research awards each February through ROSES. Panels of subject-matter expert scientists conduct peer reviews on all proposals. A Senior Review panel reviews all missions in the extended operations phase every three years, and all data archives every three or four years.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Operation of the Columbia Scientific Balloon Facility	The balloon support contractor contract was recompeted in FY 2022, with selection imminent.	Antarctica; Fort Sumner, NM; New Zealand; Sweden; Palestine, TX

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Quality	Astrophysics Advisory Committee	2021	Review to assess program against strategic objectives of Astrophysics science	Successful	2022
Quality	Senior Review of Operating Missions	2022	Review of Astrophysics operating missions	TBD	2025
Quality	Astrophysics Archives Programmatic Review	May 2023	Review of Astrophysics data archives	TBD	TBD
Quality	Astrophysics Advisory Committee	2022	Review to assess program against strategic objectives of Astrophysics science	TBD	2023

Other Missions and Data Analysis

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Astrophysics Directed R&T	0.0	7.9	**0.0**	9.0	0.0	0.0	0.0
Contract Administration, Audit & QA Svcs	17.7	14.8	**17.3**	19.6	19.6	19.6	19.6
Astrophysics Senior Review	0.0	0.0	**48.3**	52.5	53.1	53.7	54.1
Astrophysics Data Program	21.6	22.6	**23.6**	23.8	24.0	24.3	24.5
Astrophysics Data Curation and Archival	28.5	26.3	**28.4**	31.0	32.7	33.7	33.7
Total Budget	**67.8**	**71.5**	**117.6**	**135.9**	**129.5**	**131.2**	**131.9**
Change from FY 2022 Budget Request			**46.1**				
Percent change from FY 2022 Budget Request			**64.5%**				

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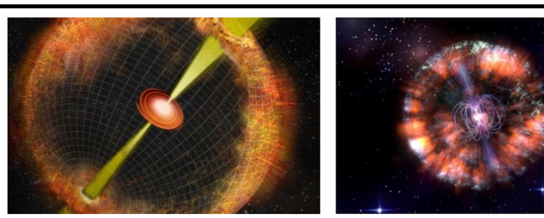

On the left, a baby black hole at the center of supernova remnant beams energy towards Earth. In this scenario, the directed energy beam is powered by the accretion of a disk of matter falling back onto the event horizon of a newborn baby black hole. The scenario shown on the right also has a directed energetic beam, but this time powered by the magnetic energy of a highly magnetized neutron star, or magnetar, left behind by the supernova. Astronomers are on the hunt for more such events to see if they can figure out if either scenario is correct.

Astrophysics Research Other Missions and Data Analysis includes the Astrophysics senior review project, the data program including data curation and archival, support for contract audits and contract quality assurance for the Science Mission Directorate, and Astrophysics directed research and technology.

Mission Planning and Other Projects

Directed Research and Technology

This project funds the civil service staff that will work on emerging Astrophysics projects, instruments, and research.

Contract Administration, Audit, and Quality Assurance Services

This project provides critical safety and mission product inspections as well as contract audit services from the Defense Contract Management Agency and Defense Contract Audit Agency, respectively. It also provides for contract assurance audits, assessments, and surveillance by the NASA Contract Assurance Services Program.

OTHER MISSIONS AND DATA ANALYSIS

ASTROPHYSICS SENIOR REVIEW

Every three years, the Astrophysics division conducts a Senior Review to perform evaluations of missions that have successfully completed, or are about to complete, their prime mission operation phase. The Senior Review findings help NASA prioritize which missions will receive funding for extended operations. The 2019 Senior Review found that NASA's fleet of operating astrophysics missions constitute a "portfolio of extraordinary power" and recommended that NASA continue their operations. The next Senior Review will take place in spring 2022.

ASTROPHYSICS DATA ANALYSIS PROGRAM (ADAP)

ADAP solicits research that emphasizes the analysis of NASA space astrophysics data archived in the public domain at one of NASA's Astrophysics Data Centers. NASA's archival astronomical data holdings continue to grow with the ongoing successful operation of a portfolio of missions. The missions range from modest Explorer-class like the Nuclear Spectroscopic Telescope Array (NuSTAR) and the Transiting Exoplanet Survey (TESS) to the great observatories Hubble and Chandra. In FY 2023, data from the recently launched Imaging X-ray Polarimetry Explorer (IXPE) will be available for analysis through ADAP. Investigations funded under the ADAP ensure that data holdings continue to be the subject of vigorous scientific research, thereby maximizing the scientific return on NASA mission investments.

The ADAP portfolio includes focused investigations that involve the analysis of archival data from a single mission, as well as broader investigations that combine data from multiple missions and span a wide wavelength range. Such multi-mission, multi-wavelength studies are a unique and exciting aspect of the program. The combinations of data collected by different missions operating in different regions of the spectrum often yield scientific insights that are unobtainable through analysis of the individual data sets alone.

Recent Achievements

During FY 2021, ADAP supported almost 150 science investigations at academic institutions, NASA centers, and other Federal laboratories across the country. Much of that funding goes to support early-career scientists—undergraduate and graduate student researchers as well as postdoctoral associates—that represent the next generation of astronomers and astrophysicists.

Archival data from the Near-Earth Object Wide-field Infrared Survey Explorer (NEOWISE) mission, the Spitzer Space Telescope, and Hubble suggest that brown dwarfs formed when the galaxy was young might be far more numerous than expected, hinting that star formation was quite different than it is today.

ASTROPHYSICS DATA CURATION AND ARCHIVAL RESEARCH (ADCAR)

Astrophysics Data Centers constitute an ensemble of archives receiving processed data from individual missions and making them accessible to the scientific community. After the completion of a mission, the relevant, active, multi-mission archive takes over all data archiving activities. ADCAR covers the activities of the Astrophysics Data Centers and the NASA Astronomical Virtual Observatories (NAVO).

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

In FY 2021, the Astrophysics Data System (ADS), which is one of the Astrophysics Data Centers, began an expansion of its database to cover publications in Heliophysics and Planetary Science, in support of NASA's interdisciplinary research efforts. The ADS data holdings have increased to 15.9 million records and 142 million citations, an increase of seven percent and nine percent year-over-year, respectively.

The scientific impact of the Mikulski Archive for Space Telescopes (MAST) included 998 refereed papers using MAST mission data in FY 2021. MAST launched a new interface for mission data that has scientific accessibility and accessible computing designed in from the start. MAST's cloud data program drove new levels of data access, with more than 1,000 terabytes (TB) of cloud data accessed in a typical month.

In FY 2021, the High Energy Astrophysics Science ARhive Center (HEASARC) served a billion data files, totaling 320 TB, and roughly nine million catalog queries. FY 2021 also saw the release of the HEASARC@SciServer service, allowing users to easily log in to a platform where data and software are immediately available for analysis through a Web browser, increasing accessibility for those with limited local computational capability.

In FY 2021, the Infrared Science Archive (IRSA) responded to 32 million queries and IRSA data appeared in approximately 1,800 refereed astrophysics journal articles. IRSA made available the 2021 NEOWISE Data Release, and a large, simulated galaxy catalog to support analysis of NASA's upcoming cosmology surveys such as those by the upcoming missions Euclid and Roman. IRSA also made significant improvements to the user interface.

The NASA/Infrared Processing & Analysis Center Extragalactic Database (NED) responded to more than 115 million queries for data and received acknowledgment in 627 peer-reviewed astrophysics journal articles. In FY 2021, the holdings grew twice as fast as in FY 2020. NED enhanced the user interface, updated systems to strengthen cybersecurity, and improved interoperability with ADS and other NASA archives.

In FY 2021, NAVO added a performance monitoring framework to help ensure its services remain responsive as the data rates increase. NAVO continues to further integrate virtual observatory services into interactive user interfaces and is planning enhancements of virtual observatory protocols to address the coming era of big data.

COSMIC ORIGINS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Hubble Space Telescope (HST)	93.3	98.3	**93.3**	98.3	98.3	98.3	98.3
James Webb Space Telescope	414.7	175.4	**172.5**	187.0	187.0	187.0	187.0
Other Missions and Data Analysis	110.5	45.2	**32.7**	31.2	31.0	31.3	31.3
Total Budget	**618.5**	**318.9**	**298.5**	**316.5**	**316.3**	**316.6**	**316.6**
Change from FY 2022 Budget Request			**-20.4**				
Percent change from FY 2022 Budget Request			**-6.4%**				

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Shown here is a Hubble Space Telescope image of the star AG Carinae and its surrounding shell of gas and dust. Like a cosmic birthday cake candle, observers took this image to celebrate the Hubble Space Telescope's 31st anniversary. Credit: NASA, ESA, STScI

"How did we get here?" This simple but fundamental question drives the broad science objectives of NASA's Cosmic Origins program. The search for answers raises underlying questions and topic areas, such as: How and when did the first stars and galaxies form? When did the universe first create the elements critical for life? How did galaxies evolve from the very first systems to the types we observe "in the here and now," such as the Milky Way in which we live? How do stars and planetary systems form and change over time?

Observatories collect data at different wavelengths to fully address these questions. Currently operating facilities in the Cosmic Origins program are the James Webb Space Telescope, the Hubble Space Telescope, and the Stratospheric Observatory for Infrared Astronomy (SOFIA).

EXPLANATION OF MAJOR CHANGES IN FY 2023

The James Webb Space Telescope (Webb) successfully launched in December 2021. The budget and management of Webb move back into the Astrophysics Division. The budget supports an increase of $115 million to the estimated development costs given COVID-19 impacts, technical delays, and a launch delay from October 2021 to December 2021. The budget for community science grants (general observers) is now shown in a separate project named Webb Science. NASA augmented the budget by $90 million in FY 2022-2027 to support more robust science during the operations phase.

COSMIC ORIGINS

Following the recommendation of the Astro2020 Decadal Survey "Pathways to Discovery in Astronomy and Astrophysics for the 2020s", this budget proposes the closeout of the SOFIA mission. SOFIA's annual operations budget is one of the most expensive operating missions in the Astrophysics Division, exceeded only by the James Webb Space Telescope and the Hubble Space Telescope. The Astro2020 Decadal Survey found that the science productivity of the mission is not on par with other large science missions and concluded that they do not expect dramatic improvement in SOFIA's scientific productivity. This budget includes some funding for the closeout of the SOFIA project.

HUBBLE SPACE TELESCOPE OPERATIONS

Formulation	Development	Operations

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**93.3**	**98.3**	**93.3**	**98.3**	**98.3**	**98.3**	**98.3**
Change from FY 2022 Budget Request			**-5.0**				
Percent change from FY 2022 Budget Request			**-5.1%**				

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Astronomers recently witnessed supernova SN 2020fqv explode inside the interacting Butterfly galaxies. Researchers quickly trained NASA's Hubble Space Telescope on the aftermath. Hubble delivered a ringside seat to the first moments of the ill-fated star's demise.

One of NASA's most successful and long-lasting science missions, the Hubble Space Telescope has beamed over 1 million images back to Earth, helping resolve many of the great mysteries of astronomy. The telescope helped scientists determine the age of the universe, the identity of quasars, and the existence of dark energy. Hubble launched in 1990 and is currently in an extended operations phase. The fifth servicing mission in 2009, the last visit by a Space Shuttle crew, added new batteries, gyroscopes, and instruments to extend Hubble's life even further into the future.

April 24, 2021 marked the start of Hubble's 31st year in orbit. The observatory is currently in its most scientifically productive period.

EXPLANATION OF MAJOR CHANGES IN FY 2023

This budget reflects use of available funds from prior years due to program efficiencies, resulting in fewer resources requested in FY 2023. NASA does not expect this adjustment to affect the workforce or science generated from the mission.

ACHIEVEMENTS IN FY 2021

Hubble currently has three functional gyros and no backups. Hubble has demonstrated the ability to conduct science operations with a single gyro. These three gyros should allow science operations to continue well into the mid-2020s, allowing overlap with Webb science operations. In June 2021, Hubble

HUBBLE SPACE TELESCOPE OPERATIONS

Formulation	Development	Operations

experienced a failure of Science Instrument Command and Data Handling Unit (SI C&DH) which caused science operations to cease. After extensive testing, the project swapped several spacecraft systems including the SI C&DH to a redundant side (A side, from B side) in order to resume normal operations.

NASA announced the Cycle 29 selections in July 2021. Motivated by a consistent underrepresentation of female Principal Investigators (PIs) in selected proposals, Hubble initiated a dual-anonymous peer review starting in 2018 with Cycle 26 and has now completed four rounds of this program. Statistics show a near tripling of the number of PIs who are leading their first Hubble investigation, but statistics are not yet definitive on the effect on selected female PIs.

Hubble has been monitoring Jupiter for more than a decade and discovered this year that the winds in the outermost "lane" of Jupiter's Great Red Spot are accelerating. Researchers analyzing Hubble's regular "storm reports" found that the average wind speed just within the boundaries of the storm, known as a high-speed ring, has increased by up to eight percent from 2009 to 2020. In contrast, the winds near the red spot's innermost region are moving significantly slower.

Hubble photographed the complete disintegration of the comet ATLAS while it was 100 million miles from the Sun. Scientists believe that this comet approached the Sun 5,000 years ago, at the dawn of civilization, and split into two pieces. Researchers can link this forensic evidence to the great comet of 1844 that was nearly as bright as the brightest naked-eye star, Sirius. The second fragment, called comet ATLAS, appeared near the beginning of 2020.

WORK IN PROGRESS IN FY 2022

In FY 2022 and beyond, NASA will support mission operations, systems engineering, software maintenance, ground systems support, guest-observer science grants, and the NASA Hubble Fellowship Program. Hubble continues mission life-extension initiatives, such as optimizing the use of gyroscopes and extending the lifetime of Hubble's instruments. NASA will select observations for Cycle 30 in mid FY 2022.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

NASA will release Cycle 31 call for proposals in early 2023. The Space Telescope Science Institute (STScI), which manages Hubble's science program, will select Cycle 31 science observations. Similar to other recent competitions for Hubble observing time, NASA expects requested observational orbits to outnumber the available orbits by six to one, indicating that Hubble remains one of the world's preeminent astronomical observatories.

HUBBLE SPACE TELESCOPE OPERATIONS

Formulation	Development	Operations

Project Schedule

Date	Significant Event
Jul 2021	Announcement of Cycle 29 selections
Jan 2022	Release of Cycle 30 Call for Proposals
Mar 2022	Deadline for Cycle 30 Proposal Submissions
Jul 2022	Approximate date for Announcement of Cycle 30 selections
Jan 2023	Release of Cycle 31 Call for Proposals
Apr 2023	Deadline for Cycle 31 Proposal Submissions
Jul 2023	Approximate date for Announcement of Cycle 31 selections

Project Management & Commitments

Element	Description	Provider Details	Change from Formulation Agreement
Observatory Operation	Provides safe and efficient control and utilization of Hubble, maintenance and operation of its facilities and equipment, as well as creation, maintenance, and utilization of Hubble operations processes and procedures	Provider: Lockheed Martin Lead Center: Goddard Space Flight Center (GSFC) Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Science Management	Evaluates proposals for telescope time and manages the science program	Provider: STScI/Association of Universities for Research in Astronomy (AURA) Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): European Space Agency (ESA)	N/A

HUBBLE SPACE TELESCOPE OPERATIONS

Formulation	Development	Operations

Acquisition Strategy

NASA competes all new Hubble research opportunities.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Observatory Operation	Lockheed Martin	Littleton, CO
Science Management	STScI/AURA	Baltimore, MD

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Senior Review	2019	Evaluate efficiency and productivity of Hubble operations	Recommend continuing extended operations given high value of science produced	2022, 2025, 2028
Performance	Independent Review of the NASA Hubble Fellowship Program	2021	Evaluate effectiveness and assess inclusiveness of NASA Hubble Fellowship Program	Recommend continued execution given success of program with increased attention to diversity of Fellows	TBD

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

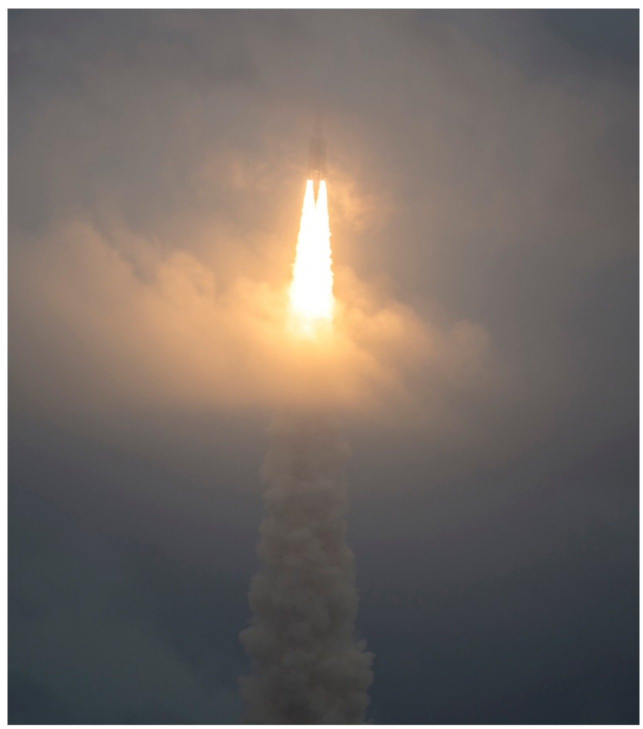
FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
James Webb Space Telescope	413.5	143.7	**121.5**	127.0	127.0	127.0	127.0
Webb Science	1.2	31.7	**51.0**	60.0	60.0	60.0	60.0
Total Budget	**414.7**	**175.4**	**172.5**	**187.0**	**187.0**	**187.0**	**187.0**
Change from FY 2022 Budget Request			**-2.9**				
Percent change from FY 2022 Budget Request			**-1.7%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The James Webb Space Telescope (Webb) is a large, space-based astronomical observatory. The mission is in many ways a successor to the Hubble Space Telescope, extending Hubble's discoveries by looking into the infrared spectrum. Webb will observe the highly red-shifted early universe and study relatively cool objects like protostars and protoplanetary disks, which emit infrared light strongly where dust obscures shorter wavelengths. With more light-collecting area than Hubble and with near- to mid-infrared optimized instruments, Webb will observe objects farther away and further back in time.



The James Webb Space Telescope is shown here launching to its destination, approximately one million miles from Earth at Lagrange Point 2.

The four main science goals are to:

- Search for the first galaxies or luminous objects formed after the Big Bang;
- Determine how galaxies evolved from their formation until now;
- Observe the formation of stars from the first stages to the formation of planetary systems; and
- Measure the physical and chemical properties of planetary systems and investigate the potential for life in those systems.

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

While Hubble greatly improved knowledge about distant objects, its infrared coverage is limited. Light from distant galaxies is red-shifted out of the visible part of the spectrum and into the infrared by the expansion of the universe. Webb will explore the poorly understood epoch when the first luminous objects in the universe came into being after the Big Bang.

EXPLANATION OF MAJOR CHANGES IN FY 2023

NASA successfully launched Webb in December 2021. Webb will begin prime mission operations after a six-month commissioning phase. NASA has split the operating budget for Webb into two separate projects: James Webb Space Telescope is the operating telescope project that supports telescope operations and the science team; and the Webb Science project contains funding for community science grants, including general observer awards.

The budget supports an increase of $115 million to the estimated development costs given COVID-19 impacts, technical delays, and a launch delay from October 2021 to December 2021. The budget supports an augmentation of $90 million to Webb Science in FY 2022-2027 to support more robust science during the operations phase.

ACHIEVEMENTS IN FY 2021

NASA made significant progress in the final stages of integration and testing of the Webb mission. The project also completed significant and technically challenging developments and tests successfully. The project completed Observatory level vibration testing, final sunshield and telescope deployment and stow, comprehensive system electrical tests, re-installation of the repaired S-band transponders, and final preparations for shipment to the launch site. Also, the project conducted testing of the Webb flight operations system and science processing system and conducted a successful operations readiness review (ORR). The project has selected cycle 1 General Observing awards for the mission.

WORK IN PROGRESS IN FY 2022

In FY 2022, NASA transported Webb to the launch site in Kourou, French Guiana where it made final preparations for spacecraft fueling. The launch campaign commenced with integration of the observatory to the launch vehicle and subsequent preparation activities of the launch vehicle. Webb successfully launched in December 2021 and traveled to its orbit in Lagrange Point 2. NASA initiated a six-month commissioning phase, first on the spacecraft, then the telescope, and finally the instruments. Once successfully commissioned, the observatory will initiate routine science operations.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

NASA plans routine science operations for FY 2023. Webb will be executing Cycle 1 observations which include the General Observer program element selected from the broad science community, the Director's Discretionary Early Release Science Program (13 programs of open public data designed to use the most common modes of the observatory) and the Guaranteed Time Observer program element (time allocated to the science instrument builder's science teams). In total, an estimated 8,000 hours of science and calibration data will be taken.

Mission Elements

JAMES WEBB SPACE TELESCOPE

Webb is an infrared-optimized observatory that conducts imaging and spectrographic observations in the 0.6- to 28-micrometer wavelength range. Webb will be roughly 100 times more capable than Hubble because its mirror is seven times larger. It will spend about twice as much time observing targets since the Earth will not be in the way. Its detectors cover larger regions of the sky and are always on (i.e., are always running in parallel), and its multi-object spectroscopic capabilities greatly expand the number of spectra per field.

The 6.5-meter primary mirror consists of 18 actively controlled segments. A multilayer sunshield the size of a tennis court passively cools the mirror, telescope optics, and instruments to about 40 Kelvin. Webb launched in 2021 from Kourou, French Guiana on an Ariane 5 rocket contributed by the European Space Agency (ESA). Webb will operate in deep space about 1 million miles from Earth.

Webb's instruments include the Near-Infrared Camera (NIRCam), Near-Infrared Spectrograph (NIRSpec), Mid-Infrared Instrument (MIRI), and the Fine Guidance Sensor/Near-Infrared Imager and Slitless Spectrograph.

The operating telescope project supports the telescope operations and science team.

WEBB SCIENCE

The Webb Science project funds research enabled by Webb observations and data. Observing time on Webb is allocated in a competitive process each year in "cycles" of awards. In order to ensure that the science community quickly learns to use its instruments and capabilities, Webb will make early awards during the first five months of Webb operations (Director's Discretionary-Early Release Science (DD-ERS)) prior to the first full cycle of research awards. DD-ERS research will range from observations of the Jovian system to studying galaxies in the distant universe. Interweaved with the DD-ERS program will be the general observer program elements from Cycle 1. The project made Cycle 1 awards in April 2021.

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

Project Schedule

Date	Significant Event
Jun 2022	Prime mission operations begin
Nov 2022	Cycle 2 Call for Proposals released
Jan 2023	Cycle 2 Proposal deadline
Apr 2023	Approximate date for announcement of Cycle 2 selections
Nov 2023	Cycle 3 Call for Proposals released
Jan 2024	Cycle 3 Proposal deadline
Apr 2024	Approximate date for announcement of Cycle 3 selections
Nov 2024	Cycle 4 Call for Proposals released
Jan 2025	Cycle 4 Proposal deadline

Project Management & Commitments

Element	Description	Provider Details	Change from Formulation Agreement
Observatory operations	Provides safe and efficient control and utilization of Webb, maintenance and operation of its facilities and equipment, as well as creation, maintenance, and utilization of Webb operations processes and procedures	Provider: STScI/Association of Universities for Research in Astronomy (AURA) Lead Center: Goddard Space Flight Center (GSFC) Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Webb Science	Evaluates proposals for telescope time and manages the science program	Provider: STScI/Association of Universities for Research in Astronomy (AURA) Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

Acquisition Strategy

The project will complete the award of the science and operations contract by September 2022 (current contract valid through December 2022).

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Science and Operations Center	STScI	Baltimore, MD

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Oct 2021	Operational Readiness Review	Confirmed project is ready for observatory operations once on orbit	N/A
Performance	Senior Review	TBD (following completion of 5-year prime mission)	Evaluate efficiency and productivity of Webb operations	TBD	TBD

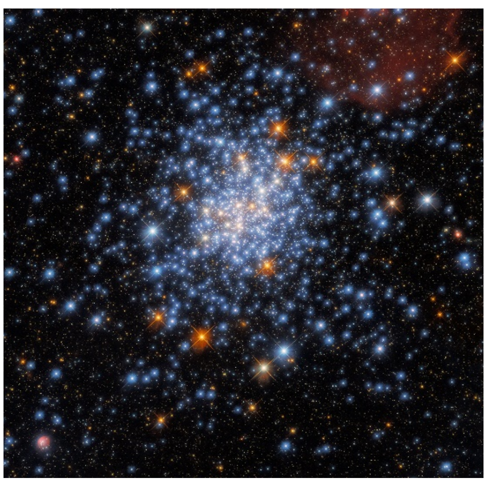
OTHER MISSIONS AND DATA ANALYSIS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Stratospheric Observ for Infrared Astron	85.2	0.0	**10.0**	0.0	0.0	0.0	0.0
Astrophysics Strategic Mission Prog Mgmt	5.8	6.7	**6.8**	6.9	6.7	6.9	7.0
Cosmic Origins SR&T	18.3	7.8	**13.9**	21.4	21.4	21.4	21.4
Cosmic Origins Future Missions	1.2	30.7	**2.1**	3.0	3.0	3.0	3.0
Total Budget	**110.5**	**45.2**	**32.7**	**31.2**	**31.0**	**31.3**	**31.3**
Change from FY 2022 Budget Request			**-12.5**				
Percent change from FY 2022 Budget Request			**-27.7%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



Shown here is a Hubble Space Telescope image of a star cluster. Stars such as the Sun form in primordial clouds of gas and dust. Clusters of stars are laboratories for understanding how they form and evolve over time. NASA's Cosmic Origins Program seeks to understand how the universe we observe came to be in its present form. Credit: ESA/Hubble & NASA, J. Kalirai, A. Milone

Cosmic Origins Other Missions and Data Analysis funds program management, supporting research and technology, and early studies of potential future Cosmic Origins missions.

Mission Planning and Other Projects

ASTROPHYSICS STRATEGIC MISSION PROGRAM MANAGEMENT

Astrophysics Strategic Mission Program Management (ASMPM) provides programmatic, technical, business management, and program science leadership for all strategic Astrophysics missions. This support continues throughout the definition, design, development, launch, and operations phases, and facilitates science investigations derived from those missions. It also provides the funding for Astrophysics Headquarters civil servants.

COSMIC ORIGINS STRATEGIC RESEARCH AND TECHNOLOGY

Cosmic Origins (COR) Strategic Research and Technology (SR&T) supports program-specific research and advanced technology development efforts, such as the Strategic Astrophysics Technology solicitation.

OTHER MISSIONS AND DATA ANALYSIS

In addition, funding supports the study of future NASA space observatories, including technology development to support recommendations of the Astrophysics Decadal Survey.

This budget request supports the continuation of the Mirror Technology Development solicitation competed in 2019. Two large teams of aerospace companies lead this on-going effort to increase performance, reduce risk and cost of future space optics. The focus is exclusively on technology maturation and elimination of some technology gaps identified during the study of the four large mission concepts submitted to the Astro2020 Decadal Review.

This budget supports a new solicitation for preparatory science investigations to meet the goals of the Astro2020 Decadal Survey "Pathways to Discovery in Astronomy and Astrophysics for the 2020s" recommendations.

Recent Achievements

During 2021, NASA, academic, and industry technologists worked on strategic COR technologies despite continued COVID-related constraints. This has led to over 150 technology infusions into space, suborbital, and ground missions/projects/strategic concepts. The COR SR&T project supported oversight of the Segmented Mirror Technology Program projects to enable the ultra-stable space telescopes needed for future flagship observatories. The project also enhanced and expanded a publicly accessible database of astrophysics technology projects. The project held its Strategic Astrophysics Technology (SAT) principal investigator annual presentation week remotely. COR assessed Technology Readiness Levels (TRL) in support of timely NASA delivery to a European Space Agency/NASA partnered mission. Finally, COR technologists continued preparing for the 2020 Decadal Survey report, to enable rapid and comprehensive response to its recommendations.

COSMIC ORIGINS FUTURE MISSIONS

Cosmic Origins Future Missions funding supports studies of future mission concepts.

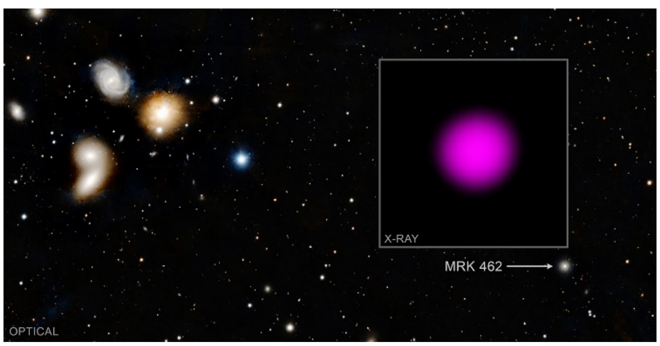
PHYSICS OF THE COSMOS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Other Missions and Data Analysis	146.4	165.8	**159.9**	188.1	182.4	182.2	177.6
Total Budget	**146.4**	**165.8**	**159.9**	**188.1**	**182.4**	**182.2**	**177.6**
Change from FY 2022 Budget Request			**-5.9**				
Percent change from FY 2022 Budget Request			**-3.6%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



Chandra has detected X-rays from the dwarf galaxy Mrk 462, which reveals the presence of a growing supermassive black hole. This black hole, pictured above, contains about 200,000 times the mass of the Sun and provides information to astronomers about how some of the earliest black holes in the Universe may have formed and grown billions of years ago. (Credit: X-ray: NASA/CXC/Dartmouth Coll./J. Parker & R. Hickox; Optical/IR: Pan-STARRS)

The universe enables scientists to study the most profound questions at the intersection of physics and astronomy. How do matter, energy, space, and time behave under extreme gravity? What is the nature of dark energy and dark matter? How did the universe grow from the Big Bang to its present size? The Physics of the Cosmos (PCOS) program incorporates cosmology, high-energy astrophysics, and fundamental physics projects that address central questions about the nature of complex astrophysical phenomena, such as black holes, neutron stars, dark matter and dark energy, cosmic microwave background, and gravitational waves.

The operating missions within the PCOS program continue to provide answers to these fundamental questions and more.

PCOS includes a vigorous program to develop the technologies necessary for the next generation of space missions to address the science questions of this program.

EXPLANATION OF MAJOR CHANGES IN FY 2023

This budget supports research and technology development in response to the Astro2020 Decadal Survey "Pathways to Discovery in Astronomy and Astrophysics for the 2020s" recommendation for a Time Domain Astronomy program.

OTHER MISSIONS AND DATA ANALYSIS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Physics of the Cosmos SR&T	45.6	60.5	**75.2**	101.1	98.6	98.4	94.1
Euclid	7.7	8.9	**9.9**	10.3	9.9	9.7	9.1
PCOS/COR Technology Office Management	6.2	11.3	**9.4**	9.8	6.9	7.2	7.4
Physics of the Cosmos Future Missions	0.1	5.9	**1.3**	3.0	3.0	3.0	3.0
Fermi Gamma-ray Space Telescope	15.9	13.9	**0.0**	0.0	0.0	0.0	0.0
Chandra X-Ray Observatory	66.8	61.4	**64.0**	64.0	64.0	64.0	64.0
XMM	4.0	4.0	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**146.4**	**165.8**	**159.9**	**188.1**	**182.4**	**182.2**	**177.6**
Change from FY 2022 Budget Request			**-5.9**				
Percent change from FY 2022 Budget Request			**-3.6%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Chandra observations, pictured here, show that a cloud of hot gas near the center of the Milky Way galaxy may be the remains of a rare type of supernova. (Credit: X-ray: NASA/CXC/Nanjing Univ./P. Zhou et al. Radio: NSF/NRAO/VLA)

Other Missions and Data Analysis supports Physics of the Cosmos (PCOS) Supporting Research and Technology, the PCOS/COR Technology Management Office, PCOS Future Missions, and operating missions including Euclid, Fermi, Chandra, and X-ray Multi-Mirror Mission (XMM).

Mission Planning and Other Projects

PCOS SUPPORTING RESEARCH AND TECHNOLOGY

PCOS Supporting Research and Technology leads strategic technology development efforts to prepare for the next generation of PCOS space missions, including program-specific research and advanced technology development efforts, such as the Strategic Astrophysics Technology (SAT) program element.

OTHER MISSIONS AND DATA ANALYSIS

NASA and the European Space Agency (ESA) are continuing to formalize the partnership for NASA's contribution to ESA's Advanced Telescope for High Energy Astrophysics (ATHENA) mission, an X-ray observatory dedicated to high-resolution spectroscopy, and ESA's Laser Interferometer Space Antenna (LISA) mission, a space-based gravitational wave observatory. This project supports the technology development and formulation activities necessary to contribute to the ESA missions.

This budget supports research and technology development in response to the Astro2020 Decadal Survey "Pathways to Discovery in Astronomy and Astrophysics for the 2020s" recommendation for a Time Domain Astronomy program.

Recent Achievements

NASA approved the Formulation Authorization Document to formally transition ATHENA from study phase to a project in September 2021. The team at Marshall Space Flight Center (MSFC) completed the study to evaluate the existing X-Ray Cryogenic Facility (XRCF) mirror handling system's (hexapod) capability to handle the ATHENA mirror structure for the calibration studies and determined that the existing hexapod mechanism can handle the ATHENA mirror. The team also initiated procurements for the ground support equipment such as metrology and control systems for the XRCF upgrades.

NASA shipped the completed laser for the LISA mission to ESA in July 2021 for one year of performance testing. NASA continues the hardware testing for the charge management device (CMD) to prepare for Technical Readiness Level-6 (TRL-6) development. Telescope structural thermal model development is on schedule. NASA has developed the engineering model mirrors and is proceeding with further testing.

EUCLID

NASA is collaborating on Euclid, an ESA mission, selected as part of ESA’s Cosmic Visions program in June 2012 and scheduled for launch in 2022. Euclid seeks to investigate the accelerated expansion of the universe, the so-called “dark energy,” using a Visible Instrument and a Near Infrared Spectrometer and Photometer instrument, as well as ground-based data. The Euclid Consortium, comprised of over 1,200 scientists and engineers from over 50 institutes in Europe, the United States, and Canada, is responsible for development of the two instruments and the science data centers. NASA contributes flight detector subsystems for the Near Infrared Spectrometer and Photometer instrument and a NASA Euclid Science Center that forms part of the Euclid Science Ground System. In exchange, NASA receives membership in the Euclid Science Team and Consortium and competed science opportunities for United States investigators.

Recent Achievements

NASA is responsible for the software development handled through the Infrared Processing and Analysis Center and the Euclid NASA Science Center at IPAC. NASA delivered various versions of the software to ESA and continues to improve the additional versions. This software deals with data handling and Euclid science products generation at the United States node. Additionally, United States Euclid team members are providing expert support and consultation to ESA during the integration and testing as required.

The NASA science team members continued to provide key, critical roles in preparing for the Euclid science survey data, providing a robust method to calibrate Euclid's photometric redshift survey, and

OTHER MISSIONS AND DATA ANALYSIS

identifying optimum observation strategies. These efforts will lead to system performance that exceeds the baseline plan for the spectroscopic survey.

PCOS/COR TECHNOLOGY OFFICE MANAGEMENT

The PCOS/COR Technology Office provides programmatic, technical, and business management for all technology development activities within the PCOS and COR programs, as well as program science leadership.

Recent Achievements

NASA continues to work with the scientific community for design studies and technology development to prepare the response to the 2020 Astronomy and Astrophysics Decadal Survey.

PCOS FUTURE MISSIONS

PCOS Future Missions funding supports concept studies of future missions.

Operating Missions

FERMI

The Fermi Gamma-ray Space Telescope explores extreme environments in the universe, from black holes on all scales, to ultra-dense neutron stars spinning thousands of times per second, to expand knowledge of their high-energy properties. Fermi observations are answering long-standing questions across a broad range of topics, including solar flares, the origin of cosmic rays, and the nature of dark matter. NASA's Fermi mission launched in June 2008, developed in collaboration with the United States Department of Energy, along with important contributions from academic institutions and partners in France, Germany, Italy, Japan, Sweden, and the United States. Fermi entered extended mission operations in August 2013. The 2019 Senior Review of Operating Missions recommended continuing Fermi operations through FY 2022. The 2022 Senior Review of Operating Missions will review Fermi extended mission operations for FY 2023 and beyond.

Recent Achievements

Fermi detected a giant flare from a highly magnetized neutron star (called a magnetar) in a nearby galaxy. Magnetar giant flares are huge eruptions observed within our own galaxy or its Magellanic Cloud satellites approximately once every 50 years and this latest flare was the first identified with a magnetar outside our galactic neighborhood. Subsequent analysis of archival Fermi data suggests that a handful of similar magnetar giant flares from nearby galaxies may have been detected by Fermi and other gamma-ray telescopes but had been masquerading as bursts of gamma rays known to arise from the deaths of stars in much more distant galaxies. The ability to pinpoint this most recent flare to its host galaxy sprang from its detection by NASA and other agency satellites, and subsequent processing by the InterPlanetary Network, a system in operation since the 1970s which uses the arrival times of signals at widely separated spacecraft to triangulate a precise origin on the sky for the signal.

OTHER MISSIONS AND DATA ANALYSIS

The instrument team published a catalog detailing the spectral analysis of over ten years and 2,200 Gamma-Ray Bursts (GRB) detected by the Fermi Gamma-Ray Burst Monitor (GBM) in 2021. This follows the ten-year catalog of basic properties of GBM-detected GRBs and the second catalog of Fermi Large Area Telescope (LAT)-detected GRBs, both published in 2020. These catalogs provide the scientific community with updated analyses and population studies by the instrument teams that can guide their investigations of the Fermi data which are all available through the NASA archives.

CHANDRA

Launched in 1999, Chandra is transforming our view of the universe with its high-quality X-ray images, providing unique insights into violent events and extreme conditions such as explosions of stars, collisions of galaxies, and matter around black holes. Chandra enables observations of clusters of galaxies that provide direct evidence of the existence of dark matter and greatly strengthens the case for the existence of dark energy. Observations of the remains of exploded stars, or supernovas, have advanced our understanding of the behavior of matter and energy under extreme conditions. Chandra has also discovered and studied thousands of supermassive black holes in the centers of distant galaxies. The 2019 Senior Review of Operating Missions recommended continuing Chandra operations as long as the observatory remains highly capable scientifically. The 2022 Senior Review of Operating Missions will review Chandra extended mission operations for FY 2023 and beyond.

Recent Achievements

Astronomers using an effect called gravitational lensing have used Chandra to study the growth of supermassive black holes at a time when the universe was only two billion years old. The gravity of a galaxy between the black-hole system and Chandra amplified and slightly displaced the X-ray signal from the black-hole system. This effect allows astronomers to study the black hole system as if it were much closer to Chandra and to conclude that the X-rays come from two distinct sources: either two growing supermassive black holes or a growing supermassive black hole and a jet.

Scientists may have found the neutron star remaining after the explosion of Supernova 1987 A. Using data from Chandra, NASA's Nuclear Spectroscopic Telescope Array (NuSTAR), and the ground-based Atacama Large Millimeter Array (ALMA), scientists may have identified the signal from a pulsar wind nebula requiring the presence of a neutron star at its core. Continued observations of this young neutron star could confirm its nature and over the next decade reveal the birth of a pulsar.

Astronomers have detected X-ray emissions from the planet Uranus. Using Chandra observations separated by 15 years, astronomers are detecting X-ray emissions scattered from incident sunlight from Uranus, Jupiter, and Saturn. The later observations suggest Uranus may also produce X-rays via a second mechanism, either joining Saturn as a source of X-rays coming from its rings or joining Jupiter as a source of auroral emission.

X-RAY MULTI-MIRROR MISSION (XMM)

XMM is an ESA-led mission with substantial NASA contributions. The telescope launched in December 1999 and provides unique data for studies of the fundamental processes of black holes and neutron stars. XMM studies the evolution of chemical elements in galaxy clusters and the distribution of dark matter in galaxy clusters and elliptical galaxies. The 2019 Senior Review of Operating Missions recommended

OTHER MISSIONS AND DATA ANALYSIS

continuing United States science operations through FY 2022. The 2022 Senior Review of Operating Missions will consider a proposal for extended United States science operations in FY 2023 and beyond.

Recent Achievements

Using observations of a supernova remnant, XMM has helped elucidate the origin and composition of cosmic rays. Combining XMM data with very high energy gamma-ray data obtained by the ground-based High Energy Stereoscopic System (HESS) and with knowledge of the interstellar medium obtained from Australia Telescope Compact Array and the Parkes Radio Telescope, scientists calculate that the charged particles flowing from this source comprise about 2/3 protons and 1/3 electrons and confirm supernova remnants as a likely source of cosmic rays.

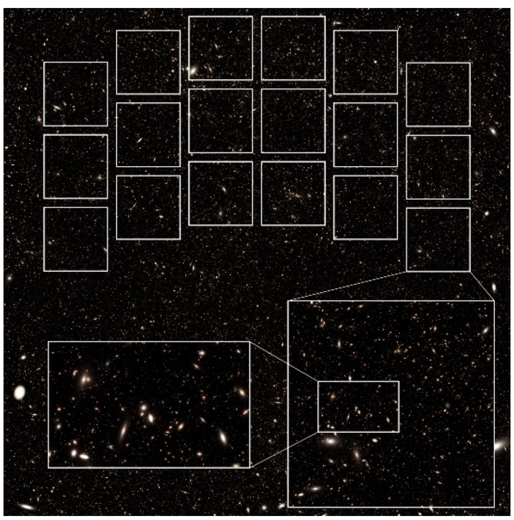
EXOPLANET EXPLORATION

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Nancy Grace Roman Space Telescope	505.2	501.6	**482.2**	407.3	380.0	345.7	216.6
Other Missions and Data Analysis	47.2	43.1	**40.0**	42.9	43.0	42.7	41.4
Total Budget	**552.4**	**544.7**	**522.2**	**450.2**	**423.0**	**388.4**	**258.0**
Change from FY 2022 Budget Request			**-22.5**				
Percent change from FY 2022 Budget Request			**-4.1%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



This synthetic image visualizes what a Roman ultra-deep field could look like. The 18 squares at the top of this image outline the area Roman can see in a single observation, known as its footprint. The inset at the lower-right zooms into one of the squares of Roman's footprint, and the inset at the lower-left zooms in even further. The image, which contains more than 10 million galaxies, was constructed from a simulation that produced a realistic distribution of the galaxies in the universe. Roman could peer across more than 13 billion years of cosmic history, reaching back to when the universe was approximately half a billion years old.

Humankind is gaining insight into timeless questions: Are we alone? Is Earth unique, or are planets like ours common? One of the most exciting new fields of research within the NASA Astrophysics portfolio is the search for planets, particularly Earth-like planets, around other stars.

Since the discovery of the first exoplanets in the 1990s, astronomers have confirmed over 4,200 planets orbiting most types of stars in our galaxy. At first, most of the planets discovered were so-called “Hot Jupiters”— gas giants similar in size to the planet Jupiter but orbiting much closer to their parent stars. However, analysis of the complete Kepler data set shows that smaller planets, with sizes between Earth and Neptune, are more common, but without counterpart in our solar system. Rocky planets in the habitable zone of their parent stars also appear to be common. The Transiting Exoplanet Survey Satellite (TESS) mission is now discovering many more small planets orbiting bright stars.

NASA’s Exoplanet Exploration Program is advancing along a path of discovery leading to a point where scientists can directly study the atmospheres and surface features of habitable, rocky planets like Earth around other stars in the solar neighborhood. In the future, NASA aims to develop systems that will allow scientists to take the pivotal step from identifying an exoplanet as Earth-sized to determining whether it is truly Earth-like, and possibly even detecting if it bears the fingerprints of life. Such an ambitious goal would require overcoming significant technological challenges. An important

EXOPLANET EXPLORATION

component of the Exoplanet Exploration effort is a robust technology development program with the goal of enabling a future direct detection and characterization mission.

EXPLANATION OF MAJOR CHANGES IN FY 2023

The Nancy Grace Roman Space Telescope (Roman) budget reflects the 2021 replan incorporating COVID-19 impacts to the mission. This replan's estimated costs for COVID-19 impacts were less than NASA's estimate at the time of the FY 2022 Budget. The new launch date of May 2027 is more than six months after the schedule baseline established at confirmation, resulting in a mission breach which NASA reported to Congress in July 2021.

The Exoplanet Exploration Science Research and Technology budget discontinues support of the Starshade effort as it is not a priority of the Astro2020 Decadal Survey "Pathways to Discovery in Astronomy and Astrophysics for the 2020s" recommendations.

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

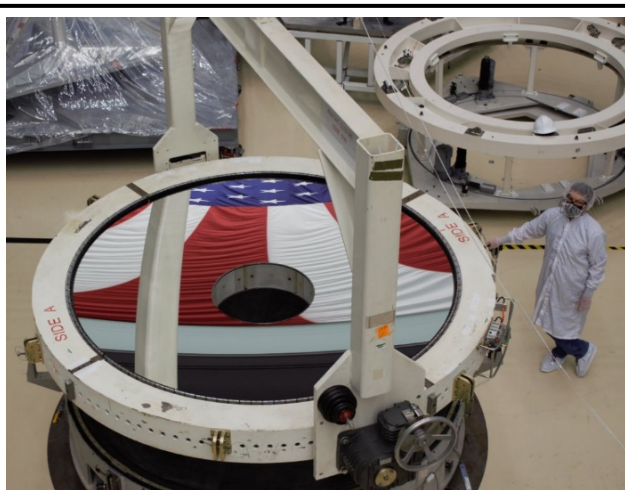
FY 2023 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027	BTC	Total
Formulation	633.8	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	633.8
Development/Implementation	527.6	505.2	501.6	**482.2**	407.3	380.0	337.1	129.1	0.0	3,270.0
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	8.6	87.5	316.0	412.2
2022 MPAR LCC Estimate	**1,161.4**	**505.2**	**501.6**	**482.2**	**407.3**	**380.0**	**345.7**	**216.6**	**316.0**	**4,316.0**
Total Budget	**1,161.4**	**505.2**	**501.6**	**482.2**	**407.3**	**380.0**	**345.7**	**216.6**	**316.0**	**4,316.0**
Change from FY 2022 Budget Request				**-19.4**						
Percent change from FY 2022 Budget Request				**-3.9%**						

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The 2022 MPAR LCC Estimate reflects the Fiscal Year 2022 Quarter 1 Financial Report, which is current as of December 2021. The requested budget authority is the project's current budget requirements which have seen programmatic changes approved by NASA since December 2021.



The Nancy Grace Roman Space Telescope is a NASA observatory designed to tackle essential questions in the areas of dark energy, exoplanets, and infrared astrophysics.

PROJECT PURPOSE

The Nancy Grace Roman Space Telescope (or Roman, for short) will investigate long-standing astronomical mysteries, such as the force behind the universe's accelerating expansion, and search for distant planets beyond our solar system. Roman will unravel the secrets of dark energy and dark matter, search for and image exoplanets, and explore many topics in infrared astrophysics. This newest NASA observatory addresses the top priority large mission of the 2010 Decadal Survey in Astronomy and Astrophysics.

Roman carries two instruments. The Wide Field Instrument will accomplish the mission's primary science over large areas of the sky. The Coronagraph Instrument technology

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

demonstration instrument matures components and systems for imaging and spectroscopy of individual nearby exoplanets. NASA has timed Roman's launch in the mid-2020s so that Roman mission's operations overlap with those of the James Webb Space Telescope to provide synergistic science capabilities. Roman ushers in a new era of big data for astrophysics, producing an archive of approximately 10 terabytes of data per day of operations. Teams at NASA's Goddard Space Flight Center, the Space Telescope Science Institute, and the Infrared Processing and Analysis Center will conduct operations.

EXPLANATION OF MAJOR CHANGES IN FY 2023

NASA completed its assessment of COVID-19 impacts on mission cost and schedule in the summer of 2021 and approved new cost and schedule estimates for the mission which are reflected in this budget submission. The resulting budget was less than the estimated COVID-19 impact included in the FY 2022 President's Budget. The new launch date of May 2027 is more than six months after the schedule baseline established at confirmation, resulting in a mission breach which NASA reported to Congress in July 2021.

PROJECT PARAMETERS

The Nancy Grace Roman Space Telescope is a NASA observatory designed to investigate essential questions in the areas of dark energy, exoplanets, and infrared astrophysics. To address these questions, the telescope has a large, 7.9-foot (2.4-meter) diameter primary mirror, since a larger surface area gathers more light and produces images that are sharper. Roman's mirror is the same size as the Hubble Space Telescope's primary mirror, and it is less than one-fourth the weight, only 410 pounds (186 kilograms), thanks to major improvements in technology. To make Roman's sensitive measurements possible, the telescope observes from a vantage point orbiting about 930,000 miles (1.5 million kilometers) away from Earth in the direction opposite the Sun. Near this location, called the second Sun-Earth Lagrange point or L2, the observatory requires little propellant to maintain a steady orbit with very little disturbance, thanks to the balance of gravitational forces.

The Roman Wide Field Instrument is a 300-megapixel infrared camera and spectrometer built to provide revolutionary surveys of unprecedented size, sharpness, and depth to address key topics in cosmology, exoplanets, and infrared astrophysics. It has a field of view that is 200 times greater than the Hubble Space Telescope's infrared instrument, allowing it to capture more of the sky with less observing time. The camera features eight filters for different wavelengths of infrared light suited to studying varied astronomical objects, plus two spectroscopic elements to measure distances and other characteristics of galaxies and supernovae across the universe.

In addition to the Wide Field Instrument, Roman will advance exoplanet observations by carrying the first active coronagraph into space. The Coronagraph Instrument, built as a technology demonstration, combines multiple technologies and operation modes to block or null the light from bright nearby stars and allow high-contrast imaging of faint exoplanets orbiting those stars. This capability is critical for next-generation telescopes capable of analyzing the atmospheres of Earth-like planets around other stars.

The Nancy Grace Roman Space Telescope is planning for a primary mission lifetime of five years, with enough propellant for a five-plus-year extended mission.

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

ACHIEVEMENTS IN FY 2021

Despite COVID-19 restrictions and continued disruptions in domestic and international supply chains, Roman made significant progress. Some notable milestones achieved in FY 2021 include:

All major elements of the Roman Space Telescope completed Critical Design Reviews (CDR). The year culminated with a Mission Critical Design Review in September 2021, resulting in a solid plan to complete development and achieve launch and on-orbit operations. Successful completion of this milestone allows the team to proceed with full-scale assembly and testing of Roman.

As NASA nears completion of the design work, the project is building and exercising the engineering development and test units, and will fabricate, test, and assemble flight hardware. The project has delivered, tested, and certified all eighteen sensor chip assemblies for the Wide Field Instrument, the most critical components of the camera, along with all six flight spare sensor chip assemblies. The project selected eighteen additional sensor chip assemblies as test units and installed and aligned them into the Wide Field Instrument mosaic plate assembly. The assembly is undergoing testing. The Wide Field Instrument received the optical bench from the manufacturer and started integration in preparation for testing. The optical bench will house the large element wheel and optical filters, along with essential electronics. The primary, secondary, and tertiary mirrors in the Optical Telescope Assembly have completed polishing. Assembly into mounting structures and testing are on-going to confirm strength and optical performance meet the strict requirements for the observatory. Electronics that will drive fine pointing of the optics are making significant progress. The project is fabricating the instrument carrier and spacecraft bus that provide structural, communications, power, and thermal services to the observatory. In addition to the test units and flight hardware, the project is building ground support equipment and software that will be critical for successful testing and operations.

In FY 2021, the Coronagraph Instrument team successfully demonstrated Technology Readiness Level six (TRL-6) for the Deformable Mirrors technology, completing all technology demonstration requirements ahead of schedule. The team has further completed the development of the flight deformable mirrors modules. The project completed engineering development units for all electronics and delivered for use in the Coronagraph Instrument Functional Testbed, where the project is demonstrating flight software functionality. Many flight parts are in fabrication or have been procured or contributed, including but not limited to delivery of four U.S. provided off-axis parabolas, four internationally contributed off-axis parabolas from Centre National d'Études Spatiales/Laboratoire d'Astrophysique de Marseille, and the internally developed flight fast steering mirror mechanism. The Coronagraph Instrument team completed all the subsystem peer reviews and subsystem CDRs leading up to the successful Coronagraph Instrument CDR held in April 2021. The European Space Agency made progress on the contributed electron multiplying charge coupled device flight detectors and plans to deliver by the Coronagraph Instrument need date.

Even with ongoing pandemic restrictions and impacts at NASA facilities and JPL, on foreign contributors, and the supply chain, the Roman mission team has maintained solid developmental progress on the overall schedule.

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

WORK IN PROGRESS IN FY 2022

In FY 2022, NASA will focus on continued fabrication and testing for all aspects of Roman. Critical deliveries among internal teams will allow progressive integration of components and testing of subassemblies, where it is most cost-effective to address any unexpected results. NASA will complete the Optical Telescope Assembly forward optical assembly struts, enabling testing with the imaging optical assembly prior to integration with the instrument carrier. The Primary Mirror Assembly, Forward Structural Assembly, Auto-Collimating Flat, and Forward Optical Assembly - all major elements of the Optical Telescope Assembly - will be ready for integration. Key electronics for the Wide Field Instrument, as well as both the Prism and the Grating Prism (Grism) will complete testing. Designs of composite structures for the instrument carrier, launch loads and vibration isolation system will be complete, and fabrication will be in work. NASA plans to procure the Roman launch vehicle in FY 2022. This allows the team to refine test parameters based on the launch loads, increasing confidence that test conditions will closely mimic the actual launch environment.

In FY 2022, the Coronagraph Instrument team continues to make progress on all of its flight and engineering development unit hardware. Test plans are in place to verify assembly level and subsystem level functionality prior to integration to the system level. NASA verified flight software functionality on the Coronagraph Instrument processor and thermal control system with plans in place to utilize engineering development hardware configured in a functional testbed for verification of all flight software components of the Coronagraph Instrument. The Coronagraph team has a robust plan in place to assemble and test its two major subsystems. The aligned optical bench, and the populated electronics heat transport pallet, prior to system level integration is scheduled to begin in late FY 2022. The Coronagraph project will hold the System Integration Review (SIR) in the third quarter of FY 2022 in preparation for system level assembly, test, and verification. The team is on track to deliver the instrument for integration ahead of the Roman mission need date.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

Assembly and test of flight hardware will continue throughout FY 2023. The project will receive delivery of the Optical Telescope Assembly. This will support integration into the instrument carrier, which the project will also receive in FY 2023.

NASA plans system level assembly, test, and verification of the Coronagraph Instrument technology demonstration. Assembly of the instrument will complete in the first quarter of FY 2023. NASA will complete full functional verification of the instrument in the second quarter, environmental and performance verification in the third quarter, and close-out activities planned through the middle of the fourth quarter. All flight system verification activity plans will take advantage of those developed and executed in the Coronagraph Instrument Functional Testbed. NASA will receive fully verified flight software, with fault protection, in the first quarter of FY 2023 and will use it in the verification of the Coronagraph Instrument. Provisions exist in the plans to allow for updates to flight software as determined from system level testing. The nominal baseline plan for the test and verification of the Coronagraph Instrument will complete in FY 2023.

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2023 PB Request
KDP-C	Feb 2020	Feb 2020
CDR	Jul 2021	Sep 2021
SIR	Jul 2023	Oct 2024
Flight Readiness Review	Jun 2026	Jan 2027
Launch	Oct 2026	May 2027
Begin Phase E	Jan 2027	Jun 2027
End Prime Mission	Jan 2032	Jun 2032

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2021	2,898	>70%	2022	$3,270	13%	LRD	Oct 2026	May 2027	7

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as Joint Confidence Level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**2,898.1**	**3,270.0**	**+371.9**
Aircraft/Spacecraft	278.1	343.7	+65.6
Payloads	661.6	636.8	-24.8
Systems I&T	183.2	284.5	+101.3
Launch Vehicle	238.6	245.5	+6.9
Ground Systems	217.6	267.2	+49.6
Science/Technology	79.4	102.7	+23.3
Other Direct Project Costs	1,239.6	1389.6	+150.0

Project Management & Commitments

NASA Headquarters is responsible for the overall management of Roman and the Coronagraph Instrument (CGI). GSFC has project management responsibility for Roman. JPL has project management responsibility for CGI.

Element	Description	Provider Details	Change from Baseline
Project Management and Systems Engineering	Management of all technical and programmatic aspects of mission development and system engineering of each element and the integrated system	Provider: NASA Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Mission Science Management	Management of all project science activities from formulation through development and operations	Provider: NASA Lead Center: GSFC Performing Center(s): GSFC and partners Cost Share Partner(s): N/A	N/A

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Wide Field Instrument	Overall instrument management; in-house development of the Focal Plane System, Grism, Prism, and all subsystems other than the Ball-managed Wide Field Instrument Opto-Mechanical Assembly (WOMA)	Provider: NASA, Ball Aerospace Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Instrument Carrier	Structural Support for the Optical Telescope Assembly, Wide Field Instrument, and Coronagraph Instrument	Provider: NASA, Northrup Grumman Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Spacecraft	Main bus for Roman; providing power, electrical, thermal, and propulsion systems	Provider: NASA Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Coronagraph Instrument	Management of all technical and programmatic aspects of instrument development and system engineering of the technology demonstration for space-based exoplanet characterization	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Star Tracker, Flight Battery	Optical device that measures the positions of stars using photocells or a camera; rechargeable power source	Provider: ESA Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Electron-Multiplying Charge-Coupled Device Detectors	Devices for digital imaging under low-light conditions	Provider: ESA Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Super-polished optics and Off Axis Parabolas	Optical elements to collimate and direct light within the Coronagraph Instrument	Provider: CNES/LAM Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): CNES	N/A

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Precision Alignment Mechanisms	Mechanisms to direct light within the Coronagraph Instrument with 1-2 arcsecond pointing accuracy	Provider: Max Planck Institute for Astronomy (MPIA) Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): MPIA	N/A
Polarization Optics	Optical elements to select the polarization state of light within the Coronagraph Instrument	Provider: Japan Aerospace Exploration Agency (JAXA) Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): JAXA	N/A
Use of Ground Station	Daily use of a ground station in Japan and data transport to the Science Operations Center (SOC)	Provider: JAXA Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Launch Vehicle	Launch services for Roman on required trajectory for L2 operational orbit	Provider: TBD Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Mission Operations	Management of on-orbit operations	Provider: NASA Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Ground Control System and Science Operations and Control Center	Science Operations Center responsible for processing, analysis, and archiving of data from the observatory	Provider: Space Telescope Science Institute (STScI) Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Coronagraph Ground Control System and Science Operations and Control Center	Science Center responsible for processing and analysis of coronagraph data for infrared astronomy	Provider: Infrared Processing and Analysis Center (IPAC) Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: The Roman Space Telescope does not keep time-varying thermal distortion within one exposure (180 seconds) sufficiently low, Then: There is a possibility that the wavefront error stability requirement of 1nm, a level impossible to verify by test, will be exceeded on-orbit.	Roman will repeat observatory Structural, Thermal, Optical Performance Integrated Modeling and Analysis with higher fidelity models incorporating element level Critical Design Review (CDR) thermal and structural models to determine wavefront error stability and perform off-nominal thermal distortion analyses to account for uncertainties in the parameters of the as-built system, in order to ensure acceptable probability of success in meeting thermal distortion requirements.
If: The Roman Space Telescope does not keep mechanical vibrations, induced by reaction wheels and high-gain antenna actuation, within one exposure (180 seconds) sufficiently low, Then: There is a possibility that the wavefront error stability requirement of 1nm, a level impossible to verify by test, will be exceeded on-orbit.	Roman will refine observatory Jitter Integrated Modeling incorporating element level CDR thermal and structural models to determine wavefront error stability and perform on-orbit workarounds assessment.

Acquisition Strategy

NASA will competitively select the launch vehicle through the NASA Launch Services program. The project has awarded all other major contracts.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Optical Telescope Assembly	L3Harris	Rochester, NY
Wide Field Instrument Opto-Mechanical Assembly (WOMA)	Ball Aerospace	Boulder, CO
Sensor Chip Assemblies	Teledyne	Camarillo, CA
	Hawaii Aerospace	Honolulu, HI
Science Operations Center Support	AURA/Space Telescope Science Institute	Baltimore, MD

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

Element	Vendor	Location (of work performance)
Science Center Support	IPAC/Caltech	Pasadena, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Feb 2018	SRR/MDR: Evaluate whether Roman requirements are properly formulated to meet mission objectives and to assess the credibility of Roman's estimated budget and schedule	Proposed mission/system architecture is credible and responsive to mission requirements and constraints including resources	Oct 2019
Performance	SRB	Oct 2019	PDR: Evaluate the completeness / consistency of the Roman preliminary design in meeting all requirements with appropriate margins, acceptable risk, and within cost and schedule constraints; and to determine readiness to proceed with the detailed design phase	Roman's planning, technical, cost and schedule baselines developed during Formulation are complete	Sep 2021
Performance	SRB	Sep 2021	CDR: Demonstrate maturity of the Roman design is appropriate to meet requirements and support proceeding with full-scale fabrication and assembly	Roman's detailed design is expected to meet requirements with adequate margins at an acceptable level of risk and there is high confidence in the baseline to allow the project to proceed with fabrication, assembly, integration, and test	Oct 2024

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Oct 2024	SIR: Determine Roman readiness to proceed to system integration and test phase	TBD	Feb 2026
Performance	SRB	TBD	LRR: Evaluate the readiness of the project to operate and perform the mission	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Exoplanet Exploration SR&T	32.2	23.2	**23.3**	23.9	24.1	23.7	22.4
Exoplanet Exploration Technoloy Off Mgmt	7.5	8.1	**7.8**	8.6	8.5	8.5	8.6
Exoplanet Exploration Future Missions	0.0	4.1	**1.3**	3.0	10.5	10.5	10.5
Keck Operations	7.5	7.7	**7.5**	7.4	0.0	0.0	0.0
Total Budget	**47.2**	**43.1**	**40.0**	**42.9**	**43.0**	**42.7**	**41.4**
Change from FY 2022 Budget Request			**-3.1**				
Percent change from FY 2022 Budget Request			**-7.2%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Short-period planets, or those with orbits shorter than one day, are rare. Potential lava world TOI 1807 b, illustrated here, is the youngest example yet discovered.

Credit: NASA's Goddard Space Flight Center/Chris Smith (KBRwyle)

Mission Planning and Other Projects

Exoplanet Exploration Other Missions and Data Analysis includes funding for Exoplanet Exploration Supporting Research and Technology, Exoplanet Exploration Technology Office Management, Keck Operations, and funding for future mission selections.

EXOPLANET EXPLORATION STRATEGIC RESEARCH AND TECHNOLOGY

Exoplanet Exploration Strategic Research and Technology supports program-specific strategic research and technology development activities to enable future NASA space missions to discover and understand distant worlds.

NASA currently supports 11 competitively selected exoplanet science and technology development projects involving researchers from across the Nation. The selected projects focus on detecting the presence of potentially habitable, Earth-sized planets orbiting Sun-like stars in the solar neighborhood and advancing technologies for isolating and studying the feeble reflected light of those planets from the overwhelming glare of their parent stars. Those technologies will one day enable a mission capable of the goal of imaging and measuring the spectra of habitable, Earth-like exoplanets orbiting Sun-like stars in our solar neighborhood.

NASA also supports a range of exoplanet science investigations through its investments in the Keck Observatory in Hawaii and the Wisconsin-Indiana-Yale-National Optical Astronomy Observatory

OTHER MISSIONS AND DATA ANALYSIS

(WIYN) Telescope in Arizona. Those science investigations include ground-based, follow-up observing programs that support NASA's Transiting Exoplanet Survey Satellite (TESS) mission as well as programs that support the operational planning and design of future missions.

The Exoplanet Exploration Science Research and Technology budget discontinues support of the Starshade effort as it is not a priority of the Astro2020 Decadal Survey "Pathways to Discovery in Astronomy and Astrophysics for the 2020s" recommendations.

Recent Achievements

The NASA Exoplanet Archive is the world-leading archive of information on exoplanets and their host stars. The archive holds data on more than 4,500 confirmed planets and has been used in over 1,000 refereed scientific publications. The Exoplanet Archive directly supports the TESS mission through the coordination of a planetary candidate follow-up program with scientists confirming 169 planets from the 4,663 candidates identified so far by TESS.

EXOPLANET EXPLORATION TECHNOLOGY OFFICE MANAGEMENT

Exoplanet Exploration Technology Office Management provides scientific and technical leadership and business management for the program's portfolio of technology development projects. It coordinates, supports, and tracks the progress of the program’s numerous technology development tasks. It also manages shared testbed infrastructure for the use of the community of exoplanet technologists, actively engages science community stakeholders, and provides effective public and professional communication of exoplanet science discovery and enabling technologies.

Recent Achievements

Exoplanet Exploration Technology Office Management supported the 2021 Sagan Summer virtual workshop in July 2021 to facilitate community collaboration.

EXOPLANET EXPLORATION FUTURE MISSIONS

Exoplanet Exploration Future Missions funding supports the execution of the exoplanet mission science and technology definition teams, and, ultimately, the formulation, development, and implementation of a future Exoplanet Exploration flight mission.

Operating Missions

KECK OPERATIONS

Keck Operations is the NASA portion of the Keck Observatory partnership. NASA is a partner for one-sixth of the observing nights on the two 10-meter telescopes of the W.M. Keck Observatory (WMKO), the largest optical telescope pair in the world. NASA uses its share of observing time in support of its Astrophysics and Planetary Science programs. The project allocates observing time for NASA astrophysics science goals, as well as for solar system objects and direct space mission support. Supported missions in recent years include Kepler, TESS, Euclid, and the Roman Space Telescope for astrophysics as well as Juno, New Horizons, and Cassini for planetary science. All observing time proposal requests

OTHER MISSIONS AND DATA ANALYSIS

are competitive with peer-review and selection managed by the NASA Exoplanet Science Institute. The Keck Observatory Archive (KOA), managed by the NASA Exoplanet Science Institute, ingests and curates existing and new data from the Keck Observatory.

Recent Achievements

The large number of proposals submitted continues to demonstrate strong demand for NASA observing nights. During the 2022A observing semester that runs from February through July 2022, scientists at institutions around the United States submitted 96 proposals requesting 193.14 nights for the available 46.5 nights. Of the proposals submitted, scientists requested 120 nights for the 25.6 nights available for general NASA strategic programs, yielding an overall general observing oversubscription rate of 4.5 for both Keck telescopes. The remaining nights requested time for on-going, high-priority key strategic mission support (KSMS) programs. NASA has reserved 62 nights for these programs over the next 2 years, leading to an oversubscription rate of 5.6 for the KSMS program. The over-subscription usually varies between three and five times as many requests for time on the telescopes than is available from semester to semester depending on the telescope, instrument, and season. The astronomical community actively uses the KOA with approximately 20 percent of WMKO publications citing the archive as the source of their data. NASA attributes the annual growth to the availability of 12 instruments in KOA covering 26 years of the "Keck Sky." Work is continuing on the NASA-approved Data Services Initiative to enhance operational efficiency and easy access to fully processed data from Keck instruments.

ASTROPHYSICS EXPLORER

FY 2022 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Spectro-Photometer for the History of the Universe, Epoch Of Reonization, and Ices Explorer	68.5	107.9	**78.7**	75.0	24.0	6.0	0.1
Other Missions and Data Analysis	135.8	157.6	**166.9**	216.4	287.3	379.0	523.1
Total Budget	**204.4**	**265.5**	**245.6**	**291.4**	**311.3**	**385.0**	**523.2**
Change from FY 2022 Budget Request			**-19.9**				
Percent change from FY 2022 Budget Request			**-7.5%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

A SpaceX Falcon 9 rocket launches with NASA's Imaging X-ray Polarimetry Explorer (IXPE) spacecraft onboard from Launch Complex 39A, Thursday, Dec. 9, 2021, at NASA's Kennedy Space Center in Florida. The IXPE spacecraft is the first satellite dedicated to measuring the polarization of X-rays from a variety of cosmic sources, such as black holes and neutron stars.

The Astrophysics Explorer program provides frequent flight opportunities for world-class astrophysics investigations using innovative and streamlined management approaches for spacecraft development and operations. The program is highly responsive to new knowledge, new technology and updated scientific priorities by launching smaller missions formulated and executed in a relatively short development cycle. NASA selects new missions based on an open competition of concepts solicited from the scientific community. The program emphasizes the accomplishments of missions under the control of the scientific research community within constrained mission life-cycle costs.

The most recent Astrophysics Medium-Class Explorer (MIDEX) missions cost up to $451 million in total, including launch services. Small Explorer (SMEX) missions cost up to $271 million including launch services. Pioneer missions cost up to $20 million, excluding the launch. The most recent Explorer Missions of Opportunity (MO) have a total NASA cost of under $100 million, including the launch. NASA intends to solicit proposals for MOs in conjunction with each Announcement of Opportunity (AO) issued for MIDEX and SMEX investigations.

ASTROPHYSICS EXPLORER

EXPLANATION OF MAJOR CHANGES IN FY 2023

The Explorer budget enables NASA to respond to recommendations from the Astro2020 Decadal Survey, "Pathways to Discovery in Astronomy and Astrophysics for the 2020s" to release an announcement of opportunity for a probe class mission no earlier than FY 2023.

ACHIEVEMENTS IN FY 2021

The Imaging X-ray Polarimetry Explorer (IXPE) successfully completed observatory integration and testing of the payload and spacecraft in September 2021.

SPHEREx successfully completed the Preliminary Design Review in October 2020, followed by the KDP-C in December 2020.

NASA selected SMEX and Explorer MO proposals for competitive Phase A mission concept studies.

WORK IN PROGRESS IN FY 2022

NASA successfully launched IXPE in December 2021.

SPHEREx completed the mission Critical Design Review (CDR) in January 2022.

NASA selected the Compton Spectrometer and Imager (COSI) in October 2021 to proceed to the preliminary design and technology completion phase (Phase B) as a SMEX mission.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

X-ray Imaging and Spectroscopy Mission (XRISM) is scheduled to launch in Spring of 2023 and will transition to phase E mission operations. Contribution to Ariel Spectroscopy of Exoplanets (CASE) plans to complete its critical design review in December 2022.

NASA expects COSI to complete its Preliminary Design Review and KDP-C in the first half of FY 2023. NASA expects the project to complete its Critical Design Review late FY 2023.

Program Schedule

Date	Significant Event
Jan 2022	Pioneers Notice of Intent due
Mar 2022	Pioneers proposals due
Summer 2022	Pioneers selections
No Earlier Than Sep 2022	Select MIDEX and Explorer MO proposals for competitive Phase A mission concept studies
No Earlier Than Jan 2023	AO announcement for Probe

ASTROPHYSICS EXPLORER

Date	Significant Event
Summer 2023	Pioneers first gate review
No Earlier Than 2024	Select Probe proposals for competitive Phase A studies
Mar 2024	AO announcement for SMEX and MO opportunity to propose
No Earlier Than Mar 2024	Down-select one MIDEX and Explorer MO mission for implementation
Mar 2025	Select SMEX and Explorer MO proposals for competitive Phase A mission concept studies
No Earlier Than 2025	Down-select one Probe mission for implementation
Aug 2026	AO announcement for MIDEX and MO opportunity to propose
Nov 2027	Down-select one SMEX and one Explorer MO for implementation

Program Management & Planned Cadence

The Astrophysics and Heliophysics Explorer Programs are both coordinated sets of uncoupled missions, where each mission is independent and has unique science. The Programs share a common program office at NASA Goddard Space Flight Center (GSFC) and a common management structure. The Explorer program manager resides at GSFC, reporting functionally to the Center Director and programmatically through the Astrophysics and Heliophysics Division Directors to the Associate Administrator for Science Mission Directorate (SMD).

This budget supports approximately a three-year mission cadence.

Acquisition Strategy

NASA selects all Explorer missions through competitive AOs.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Program Independent Review	SRB	2019	Assess performance of program	Successful	2024

SPECTRO-PHOTOMETER FOR THE HISTORY OF THE UNIVERSE, EPOCH OF REONIZATION, AND ICES EXPLORER

Formulation	Development	Operations

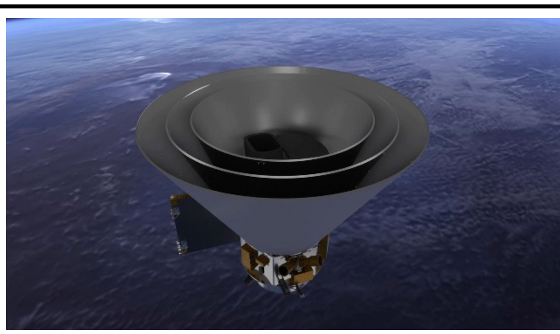
FY 2023 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027	BTC	Total
Formulation	64.2	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	64.2
Development/Implementation	27.1	68.5	107.9	**78.7**	74.6	11.0	0.0	0.0	0.0	367.8
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	13.0	6.0	0.1	0.0	19.1
2022 MPAR LCC Estimate	**91.3**	**68.5**	**107.9**	**78.7**	**74.6**	**24.0**	**6.0**	**0.1**	**0.0**	**451.0**
Total Budget	**91.3**	**68.5**	**107.9**	**78.7**	**75.0**	**24.0**	**6.0**	**0.1**	**0.0**	**451.4**
Change from FY 2022 Budget Request				**-29.2**						
Percent change from FY 2022 Budget Request				**-27.1%**						

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The 2022 MPAR LCC Estimate reflects the Fiscal Year 2022 Quarter 1 Financial Report, which is current as of December 2021. The requested budget authority is the project's current budget requirements which have seen programmatic changes approved by NASA since December 2021.



NASA's SPHEREx space observatory will use a technique called spectroscopy to measure hundreds of millions of galaxies and a rich diversity of astronomical phenomena. With the capability, SPHEREx will produce a near-infrared, three-dimensional map of the universe unlike any other. Scientists will use this map to answer big questions about the early universe, the history of galaxies, and the prevalence of life-sustaining molecules in planet-forming regions of space.

PROJECT PURPOSE

The Spectro-Photometer for the History of the Universe, Epoch of Re-ionization, and Ices Explorer Mission (SPHEREx) will serve as a powerful tool for understanding how our universe evolved and how common the ingredients for life are in our galaxy's planetary systems. SPHEREx will be NASA's first all-sky spectral astronomy survey mission and will investigate the quantum physics of the Big Bang theory of the origin of the Universe. The mission will chart the origin and history of galaxy formation, from light produced by the first galaxies that ended the cosmic dark ages, to the present day. Astronomers will use the mission to gather data on hundreds of millions of galaxies and stars. SPHEREx will also

SPECTRO-PHOTOMETER FOR THE HISTORY OF THE UNIVERSE, EPOCH OF REONIZATION, AND ICES EXPLORER

Formulation	Development	Operations

survey water and organic molecules in interstellar ices.

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

PROJECT PARAMETERS

SPHEREx is a medium Explorer-class astrophysics mission planned to launch in 2025. It is a three-axis stabilized spacecraft that NASA will launch into a sun-synchronous Earth orbit with an altitude of approximately 650 kilometers for a baseline two-year science mission. SPHEREx will survey the sky in near-infrared light. SPHEREx will probe the origin of the Universe through a large-volume galaxy redshift survey and provide a rich public spectral archive for diverse investigations. The payload consists of the thermal subsystem, optical subsystem, and instrument control electronics. The Korea Astronomy and Space Science Institute (KASI) will contribute the non-flight cryogenic test chamber. SPHEREx will launch on a SpaceX Falcon 9.

ACHIEVEMENTS IN FY 2021

The SPHEREx project completed its Preliminary Design Review (PDR) in October 2020, followed by a KDP-C confirmation review in December 2020, and entered its final design and fabrication phase (Phase C). NASA awarded the launch vehicle contract to SpaceX in February 2021.

WORK IN PROGRESS IN FY 2022

The project continues design work on the instrument control electronics and the optical subsystem for the payload, in addition to the design work of the payload thermal subsystem, and KASI work on the instrument test chamber. The project completed its mission Critical Design Review (CDR) in January 2022. The project will continue fabrication and assembly of the SPHEREx payload and spacecraft bus subsystems throughout FY 2022.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

The project will complete the fabrication and assembly of flight components of both payload and spacecraft bus in preparation for the Systems Integration Review in March 2023, and KDP-D in June 2023.

SPECTRO-PHOTOMETER FOR THE HISTORY OF THE UNIVERSE, EPOCH OF REONIZATION, AND ICES EXPLORER

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2023 PB Request
Key Decision Point (KDP)-C	Dec 2020	Dec 2020
Critical Design Review (CDR)	Sep 2021	Jan 2022
System Integration Review	Mar 2023	Mar 2023
KDP-D	May 2023	June 2023
Launch Readiness Date (LRD)	Apr 2025	Apr 2025
Phase E start	May 2025	May 2025

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2021	367.8	>70%	2022	367.8	0%	Launch Readiness Date (LRD)	April 2025	April 2025	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time was developed. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

SPECTRO-PHOTOMETER FOR THE HISTORY OF THE UNIVERSE, EPOCH OF REONIZATION, AND ICES EXPLORER

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**367.8**	**367.8**	**0.0**
Aircraft/Spacecraft	54.9	50.2	-4.7
Payloads	45.8	50.4	+4.6
Systems I&T	11.9	13.4	+1.5
Launch Vehicle	112.4	98.8	-13.6
Ground Systems	12.0	12.0	0.0
Science/Technology	21.0	21.0	0.0
Other Direct Project Costs	109.8	122.0	+12.2

Project Management & Commitments

The Jet Propulsion Laboratory (JPL) provides project management for the mission. The SPHEREx Principal Investigator resides at the California Institute of Technology (Caltech). JPL manages the overall SPHEREx mission and will provide systems engineering, mission assurance, payload thermal and mechanical mission system and the operations science team.

Element	Description	Provider Details	Change from Baseline
Payload Thermal Subsystem	The thermal subsystem consists of the photon shields, focal plan radiator, telescope support structure, and V-groove radiators	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): None	N/A
Payload Optical Subsystem	The optical subsystem consists of the baffle and focal plane assemblies	Provider: Caltech Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	N/A

SPECTRO-PHOTOMETER FOR THE HISTORY OF THE UNIVERSE, EPOCH OF REONIZATION, AND ICES EXPLORER

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Payload Electronics Subsystem	The electronics subsystem consists of the payload flight software and instrument control electronics	Provider: Caltech Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	N/A
Spacecraft	Spacecraft Bus	Provider: Ball Aerospace Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	N/A
Telescope	20cm wide-field off-axis all-aluminum telescope	Provider: Ball Aerospace Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	N/A
Focal Plane Assemblies	The two focal plane assemblies are separated by a dichroic filter to deliver full short and long wavelength coverage	Provider: JPL Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	N/A
Detectors	Each of six detector arrays has its own linear variable filters.	Provider: Teledyne Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	N/A
Test Chamber	The non-flight cryogenic test chamber will support two test modes; optical mode with an optical window, and dark mode with a cryogenic integrating sphere.	Provider: Korea Astronomy and Space Science Institute (KASI) Lead Center: JPL Performing Center(s): None Cost Share Partner(s): KASI	N/A
Launch Vehicle	Launch vehicle and related launch services	Provider: SpaceX Lead Center: KSC/Vandenberg Air Force Base (VAFB) Performing Center(s): None Cost Share Partner(s): None	N/A

SPECTRO-PHOTOMETER FOR THE HISTORY OF THE UNIVERSE, EPOCH OF REONIZATION, AND ICES EXPLORER

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: The Instrument Control Electronics (ICE) delivery is delayed, Then: The overall payload subsystem development schedule will be impacted.	SPHEREx Project has used funded schedule margins at Payload and Observatory level to substantially mitigate this risk, however, full recovery of the ICE schedule is not possible.
If: The telescope delivery is delayed, Then: The overall payload subsystem development schedule will be impacted.	SPHEREx Project is working with the vendor to identify schedule options to accommodate potential telescope delays. Further review of options will be planned at SPHEREx critical design review.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Observatory integration, spacecraft bus	Ball Aerospace	Boulder, CO
Payload detectors	Teledyne	California
Payload telescope	Ball Aerospace	Boulder, CO
Launch Vehicle	SpaceX	Hawthorne, CA
PI, CO-Is, Mission Payload	California Institute of Technology	Pasadena, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Oct 2020	PDR	Successful	Jan 2022
Performance	SRB	Jan 2022	Mission CDR	Successful	Mar 2023
Performance	SRB	Mar 2023	SIR	TBD	Feb 2024
Performance	SRB	Feb 2024	ORR	TBD	N/A

OTHER MISSIONS AND DATA ANALYSIS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Compton Spectrometer and Imager	0.0	24.3	**51.3**	87.4	71.0	28.4	5.3
Pioneers	0.0	21.3	**23.4**	23.8	32.1	35.0	40.2
Contribution to ARIEL Spectroscopy of Ex	18.0	3.6	**10.3**	8.9	4.0	2.2	2.9
Astrophysics Explorer Future Missions	5.2	15.8	**23.9**	53.9	155.0	284.8	460.7
Astrophysics Explorer Program Management	13.3	17.8	**14.0**	13.5	8.2	14.5	12.1
Neutron Star Interior Composition Explor	4.8	4.4	**0.0**	0.0	0.0	0.0	0.0
Neil Gehrels Swift Observatory	6.4	5.8	**0.0**	0.0	0.0	0.0	0.0
Nuclear Spectroscopic Telescope Array	8.6	8.6	**0.0**	0.0	0.0	0.0	0.0
Transiting Exoplanet Survey Satellite	15.2	14.1	**0.0**	0.0	0.0	0.0	0.0
Galactic/Extragalactic ULDB Spectroscopi	8.8	5.2	**1.0**	0.0	0.0	0.0	0.0
Imaging X-Ray Polarimetry Explorer	38.8	14.3	**6.9**	0.7	0.0	0.0	0.0
X-Ray Imaging and Spectroscopy Mission	16.8	22.4	**36.2**	28.3	16.9	14.1	2.0
Total Budget	**135.8**	**157.6**	**166.9**	**216.4**	**287.3**	**379.0**	**523.1**
Change from FY 2022 Budget Request			**9.3**				
Percent change from FY 2022 Budget Request			**5.9%**				

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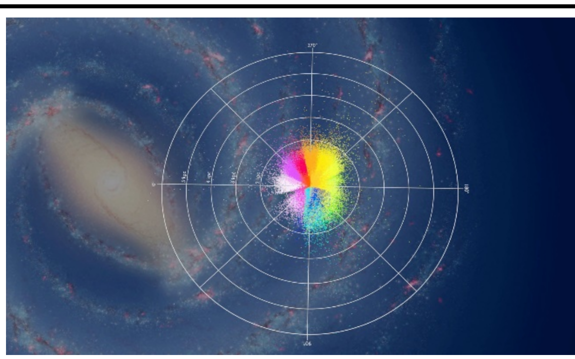
Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



This visualization shows the new sample of oscillating red giant stars (colored dots) discovered by NASA's Transiting Exoplanet Survey Satellite. The colors map to each 24-by-96-degree swath of the sky observed during the mission's first two years. The view then changes to show the positions of these stars within our galaxy, based on distances determined by the European Space Agency's Gaia mission. The scale shows distances in kiloparsecs, each equal to 3,260 light-years, and extends nearly 20,000 light-years from the Sun. Credit: Kristin Riebe, Leibniz Institute for Astrophysics Potsdam

Mission Planning and Other Projects

Astrophysics Explorer Other Missions and Data Analysis includes funding for small missions in formulation and development (CASE, SPHEREx, GUSTO, XRISM, COSI), Pioneers, operating missions (IXPE, TESS, NICER, NuSTAR, Neil Gehrels Swift Observatory), and funding for future mission selections and program management functions. FY 2023 funding for missions in extended operations will be considered as part of the spring 2022 Senior Review.

OTHER MISSIONS AND DATA ANALYSIS

ASTROPHYSICS PIONEERS

Astrophysics Pioneers is an entirely new program element within the Explorer Program first solicited in Research Opportunities in Space and Earth Sciences (ROSES)-2020. Pioneers investigations will provide high impact science with low cost via the use of new and inexpensive SmallSat and CubeSat technologies, new Ultra-Long Duration stratospheric balloon payloads, and ISS payloads. The Astrophysics Pioneers program element will solicit proposals for astrophysics suborbital and modest orbital science investigations that are greater in cost and scope than what is possible within the Astrophysics Research and Analysis (APRA) program element but are smaller in cost and scope than allowed in the Astrophysics Explorer Mission of Opportunity (MO) element. This class of small missions fills the gap between existing ROSES investigations and existing MO investigations. The program is PI-managed, each investigation is cost capped at $20M and NASA encourages new and early career researchers to participate.

Recent Achievements

In 2021 NASA announced the selection of the first four Pioneers projects. Payload for Ultrahigh Energy Observation (PUEO), a long duration balloon born instrument for particle astrophysics at the highest energies; Pandora, a SmallSat for multiwavelength characterization of exoplanets and their host stars; Aspera, a SmallSat to measure the intergalactic medium inflow/outflow from galaxies; and StarBurst, a SmallSat all-sky monitor for high energy gamma rays from events such as the merger of neutron stars -- events that can be synchronized with the detection of simultaneous gravity waves at facilities such as the ground-based Laser Interferometer Gravitational-wave Observatory (LIGO). First time principal investigators lead all four investigations. These missions all passed their first gate review in early FY 2022, at which NASA determined each mission is feasible within the $20 million cost cap and will thus continue to the implementation phase. NASA plans to solicit Pioneers annually, with the next proposals due March 2022.

CONTRIBUTION TO ARIEL (ATMOSPHERIC REMOTE-SENSING INFRARED EXOPLANET LARGE-SURVEY MISSION) SPECTROSCOPY OF EXOPLANETS (CASE)

ARIEL is a joint ESA/NASA mission planned for launch in the late 2020s that will observe hundreds of warm transiting gas giants, Neptune-sized planets, and super-Earths. The mission responds to high-priority science from the Astro2020 Decadal Survey by addressing the question: "What are the characteristics of planetary systems orbiting other stars and do they harbor life?”

ARIEL’s main science goals include measuring the composition and structure of planetary atmospheres, determining the vertical and horizontal temperature structure, and identifying chemical processes at work. A mission designed and optimized for transiting exoplanet spectroscopy will address a key gap in NASA’s exoplanet exploration mission portfolio. CASE will fill that gap and ensure the full participation of the U.S. community in ESA’s ARIEL mission. The CASE project hardware contribution to ARIEL is a pair of heritage sensor chip assemblies, cold front-end electronics, and cryogenic flex cables together with packaging and thermal management capability. CASE is currently in its formulation phase and is working with the European ARIEL consortium partners on interface requirements for the NASA contribution.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

The project has successfully tested Euclid-heritage residual detectors in the detector characterization lab at Goddard Space Flight Center for the CASE operating environment. The project recently decided to use these detectors for CASE application.

GALACTIC/EXTRAGALACTIC ULTRALONG-DURATION BALLOON SPECTROSCOPIC TERAHERTZ OBSERVATORY (GUSTO)

In March 2017, NASA's Astrophysics Explorer Program selected the GUSTO balloon payload as a Mission of Opportunity. GUSTO will launch on a high-altitude stratospheric zero pressure balloon from McMurdo, Antarctica, in December 2022 for approximately 75 days. GUSTO’s telescope, with its terahertz heterodyne array receivers, will provide the spectral and spatial resolution needed to study the interstellar medium. The GUSTO mission will provide the first complete study of all phases of the stellar life cycle, from the formation of molecular clouds, through star birth and evolution, to the formation of gas clouds and the restart of the cycle. During flight, the GUSTO payload will conduct its scientific observation while tracking the prevailing stratospheric winds at the float altitude of 33.5 kilometers.

Recent Achievements

GUSTO completed the observatory transporter fabrication and APL will complete testing in March 2022. NASA will complete assembly of the gondola and will begin observatory integration when the payload is complete and delivered to APL in spring 2022.

THE X-RAY IMAGING AND SPECTROSCOPY MISSION (XRISM)

The X-ray Imaging and Spectroscopy Mission (XRISM), previously named XARM, is a joint NASA and JAXA mission that will recover the soft X-ray spectroscopic capability lost with the Hitomi mission that ended in March 2016. JAXA is planning to launch XRISM in early 2023. The key scientific objective of XRISM is to investigate celestial X-ray objects in the Universe with unprecedented high-resolution X-ray spectroscopy. XRISM will provide breakthrough science in a number of areas, including structure and formation of the Universe, the evolution of clusters of galaxies, and the transport and circulation of energy in the cosmos. NASA is developing the Resolve Soft X-ray Spectrometer and many of its subsystems and the X-ray mirror assemblies for the observatory. NASA is also responsible for the Science Data Center, which is developing the analysis software for all instruments, the data processing pipeline, as well as support of Guest Observers (GO).

Recent Achievements

Testing of the integrated system recently revealed a small helium leak in the JAXA dewar. NASA and JAXA personnel resolved the helium leak after completing a series of comprehensive performance and thermal cycling tests in August 2021. JAXA received the flight electronics boxes in 2021 and NASA completed the X-ray Mirror Assemblies calibration in preparation for delivery to JAXA in 2022.

COMPTON SPECTROMETER AND IMAGER (COSI)

NASA selected the Compton Spectrometer and Imager (COSI) in October 2021 as the next SMEX mission. COSI will study the recent history of star birth, star death and the formation of chemical

OTHER MISSIONS AND DATA ANALYSIS

elements in the Milky Way by observing gamma-rays from radioactive elements produced when massive stars explode. The mission will also probe the origin of our galaxy's positrons, elementary particles that that have the same mass as an electron but a positive charge. NASA expects COSI to launch in 2026.

ASTROPHYSICS EXPLORER FUTURE MISSIONS

Astrophysics Explorer Future Missions funding supports future Astrophysics Explorer missions, Missions of Opportunity, and Pioneer class missions through concept studies and selections. Explorer Future funding also supports an Announcement of Opportunity (AO) release for an Astrophysics Probe mission no earlier than 2023, as recommended by the Astro2020 Decadal Survey "Pathways to Discovery in Astronomy Astrophysics for the 2020s". The first Astrophysics Probe will be one of two mission themes recommended by the Decadal Survey: either a far infrared imaging or spectroscopy probe or an X-ray probe that complements the European Space Agency's Athena mission. The Astrophysics Probe missions will be PI-led and selected using NASA's AO acquisition process. The Explorer Future funding also supports the Ultraviolet Transient Astronomy Satellite (ULTRASAT) mission. NASA is partnering with the Israel Space Agency to provide a commercial rideshare launch. NASA's role also includes Science Team membership and participation with data analyses.

Recent Achievements

NASA issued an announcement in January 2022 notifying the community of plans for the first Astrophysics Probe mission.

NASA is in the process of entering into a formal agreement with the Israel Space Agency (ISA) to provide a launch in the 2024/2025 timeframe for the ULTRASAT mission, under development by ISA.

ASTROPHYSICS EXPLORER PROGRAM MANAGEMENT

Astrophysics Explorer program management provides programmatic, technical, and business management of ongoing missions in formulation and development.

Operating Missions

NEUTRON STAR INTERIOR COMPOSITION EXPLORER (NICER)

The NICER instrument launched on June 3, 2017 to an external logistics carrier on the International Space Station (ISS) for an 18-month prime mission. Its main goal is spectroscopic X-ray observations of neutron stars with high-time resolution, to measure their masses and radii precisely and thus to test models of how matter behaves at extreme densities. A neutron star squeezes up to twice the mass of the Sun into a city-size volume, so the density and pressure are higher than in atomic nuclei. NICER measures fluctuating X-rays from other sources, such as disks of hot gas pouring onto a black hole or neutron star from a stellar companion, or the gas around very massive black holes at the centers of galaxies. The 2019 Senior Review of Operating Missions approved extended mission operations through FY 2022 to include additional cycles of the NICER Guest Observer program element. NASA will conduct the next Senior Review in the Spring of 2022 and will recommend funding allocations through FY 2025.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

NICER participated, along with two European telescopes, in the discovery of quasi-periodic X-ray eruptions (QPEs) in two previously quiescent galaxies, galaxies that stopped forming stars. The NICER data confirmed the phenomenon and provided unique spectroscopic and timing information to fully characterize this unexpected behavior. Conventional wisdom stated that changes in the emission properties of X-ray dim galaxies should occur on timescales of many years, but the nuclei of the two new QPE emitters light up in X-rays every few hours, reaching peak luminosities more than 10 times their historical low brightness levels. This pulsating behavior may be due to a stellar object orbiting the central black hole. A possible explanation for the nearly periodic X-ray emission is that a normal star or white dwarf is being partially torn apart every time it passes closest to the black hole in each hours-long orbit. Future observations will test this hypothesis. It has important implications for the possible emission of gravitational waves from such systems, by constraining changes to the frequency of the X-ray eruptions, thereby probing the nature and orbit of the massive black hole's ill-fated companion.

NEIL GEHRELS SWIFT OBSERVATORY

The Neil Gehrels Swift Observatory (Swift) remains NASA's premier mission for prompt and accurate localization of gamma-ray bursts and rapid response X-ray and Ultraviolet follow up observations of transient sources requested by the astronomical community. Swift is a multi-wavelength space-based observatory uniquely equipped to make rapid-response observations to fast-breaking events. The observatory measures the position, brightness, and physical properties of gamma-ray bursts, and is revolutionary in allowing scientists to solve the mystery of their origin in the formation of stellar-mass black holes. The observatory continues to target gamma-ray burst science, while also using its capabilities to increase our understanding of the entire transient universe, ranging in distance from the solar system to high-redshift quasars, and in time from the present to the epoch of reionization. Swift is a MIDEX class mission that launched in 2004 and is currently in extended mission operations. The 2019 Senior Review of Operating Missions recommended continuing operations through FY 2022. NASA will conduct the next Senior Review in the Spring of 2022 and will recommend funding allocations through FY 2025.

Recent Achievements

On October 23, 2021, Swift discovered its 1500th gamma-ray burst, distant cosmic explosions that briefly outshine all other sources in the gamma-ray sky put together. A subclass of these outbursts is known to be associated with merging neutron stars - the same progenitors responsible for producing signals in ground-based gravitational-wave detectors. While LIGO's gravitational-wave detectors were undergoing upgrades in 2021, Swift continued to uncover more of these "short" gamma-ray bursts, with exciting new results reported that improve our understanding of the capability of these systems to generate elements heavier than iron. Swift receives an average of five requests daily from the community to rapidly point its sensitive X-ray and Ultraviolet telescopes at targets of interest before they fade away.

In February 2021, for only the second time, astronomers linked an elusive particle called a high-energy neutrino to an object outside our galaxy. Using Swift observations and data from ground-based telescopes, astronomers traced the neutrino to a black hole tearing apart a star, a rare cataclysmic occurrence called a tidal disruption event.

Regular Swift observations, together with data from TESS, NuSTAR, and XMM-Newton, helped reveal regular ("periodic") variability from a supermassive black hole at the center of a distant galaxy. Our leading explanation of this periodicity is a partial tidal disruption, where small pieces are torn off each

OTHER MISSIONS AND DATA ANALYSIS

time a star orbits the black hole. The recurrent nova (red giant plus white dwarf binary) RS Ophiuchi underwent a new eruption in 2021, its seventh known eruption since 1898. Swift observations are helping to reveal the detailed nucleosynthesis ongoing in this system that might explode as a Type Ia supernova.

NUCLEAR SPECTROSCOPIC TELESCOPE ARRAY (NUSTAR)

Launched in June 2012, NuSTAR completed its prime mission in July 2014 and is now in extended mission operations. NuSTAR enables scientists to locate supermassive black holes in other galaxies, study extreme accretion onto neutron stars, locate and examine the remnants of collapsed stars in our Galaxy and the nearby universe, and observe any new supernovae in the local group of galaxies. NuSTAR's key science products are sensitive X-ray maps of the celestial sky at a higher energy band than any other focusing X-ray satellite. NuSTAR offers opportunities for a broad range of science investigations, ranging from probing cosmic ray origins and studying the extreme physics around collapsed stars to mapping microflares on the surface of the Sun. NuSTAR performs key follow-up observations of sources found by NASA's Chandra, Spitzer, and Wide-field Infrared Survey Explorer (WISE) satellites. The NuSTAR mission implemented a Guest Observer program in 2015. NuSTAR is now conducting the observations selected under Cycle 6 and 7 of the Guest Observer program. The project coordinates some NuSTAR observations with other missions, including Swift, Chandra, INTEGRAL, XMM-Newton, and NICER. Such coordinated observations take advantage of NuSTAR's unique access to high-energy X-rays with synergistic lower-energy X-ray capabilities of these other missions, such as NICER's exquisite X-ray timing, Chandra's high spatial resolution imaging, and Swift's agility for rapidly slewing across the sky to monitor variable sources. The 2019 Senior Review of Operating Missions recommended continuing operations through FY 2022. NASA will conduct the next Senior Review in the Spring of 2022 and will recommend funding allocations through FY 2025.

Recent Achievements

NuSTAR detected, for the first time, a light echo coming from behind a black hole. Researchers observed bright flares of X-ray emissions, produced as gas falls into a supermassive black hole. The flares echoed off the gas falling into the black hole. NuSTAR observations captured short flashes of X-rays as the flares subsided, corresponding to the reflection of the flares from the far side of the disk, and bent around the black hole by its strong gravitational field.

NuSTAR also used its unique capability as the only focusing X-ray telescope to stare directly at the sun to observe increasing activity as we approach the solar maximum. These observations also support the Parker Solar Probe mission as it makes its close approach to the sun. Besides studying the exotic super massive black holes that power the centers of galaxies and the stellar mass black holes that can devour stars in binary systems, NuSTAR has also observed the many incarnations of neutron stars. They can appear as accreting companions in binary systems, fast rotating pulsars, highly energic magnetars, and can merge to create titanic explosions known as kilonovas. These highly compacted cores of dead stars are responsible for some of the most interesting high-energy X-ray events known. NuSTAR has found that most, and maybe all, Ultra Luminous X-ray sources have neutron stars at their heart.

TRANSITING EXOPLANET SURVEY SATELLITE (TESS)

The Transiting Exoplanet Survey Satellite (TESS) mission launched on April 18, 2018. TESS is performing an all-sky survey to search for planets transiting nearby stars. By finding planets smaller than Neptune that transit stars bright enough to enable follow-up, TESS discoveries are prime targets to learn

OTHER MISSIONS AND DATA ANALYSIS

about the composition and atmospheric properties of planets beyond the solar system. TESS monitors the sky with four wide-field visible-light cameras to detect periodic drops in brightness caused by planets passing in front of their stars. TESS also obtains full-frame images of the entire field-of-view (24 x 96 degrees) at a cadence of 10 minutes and for a subset of preselected targets and collects data at a higher time-resolution of one image every 20 seconds.

TESS is designed to survey over 85 percent of the sky (an area of sky 400 times larger than covered by Kepler) to search for planets around nearby stars (within approximately 200 parsecs). TESS stars are typically 30-100 times brighter than those surveyed by the Kepler satellite. Planets detected around these stars are far easier to characterize with follow-up observations, resulting in refined measurements of planet masses, sizes, densities, and atmospheric properties. The 2019 Senior Review of Operating Missions recommended continuing operations through FY 2022. NASA will conduct the next Senior Review in the Spring of 2022 and will recommend funding allocations through FY 2025.

Recent Achievements

TESS ended its prime operations in July 2020 and is now in extended operations. TESS has identified over 4,600 candidate planets, with 166 confirmed as bona fide planets. Planet searches and ground-based observations are ongoing to find, confirm, and characterize more planets. TESS planets are among the best targets for detailed follow-up observations with large ground- and space-based telescopes such as the James Webb Space Telescope. Of the 68 exoplanets Webb will observe in its first year of science, 25 were discovered by TESS. These planets are predominantly small and potentially rocky, like Earth.

Its new data modes are enabling the study of very short duration events in unprecedented detail, such as stellar flares and pulsations, and allow detailed measurements of stellar vibrations which researchers can use to measure stars' radii, masses, densities, and ages. TESS is continuing to expand the survey to new fields and revisiting previously observed regions, which can reveal smaller planets, and wider orbits around their parent stars. While still performing exoplanet science, the breadth of the mission is expanding and now includes science that is closer to home, such as investigations of Near-Earth asteroids and comets in our Solar System, as well as studies of distant black holes through observations of active galaxies, supernovae, and optical emission from gamma-ray bursts. In addition to the hundreds of professional astronomers who regularly use TESS data, over 30,000 citizen-scientists have contributed to the discovery and follow-up of new TESS exoplanet candidates through Planet Hunters-TESS, Planet Patrol and Exoplanet Watch, collaborations between scientists and members of the public.

THE IMAGING X-RAY POLARIMETRY EXPLORER (IXPE)

NASA selected IXPE, a Small Explorer-class (SMEX) mission, in January 2017. Due to the hundred-fold improvement in the sensitivity of X-ray polarimeters during the past two decades, IXPE will enable astrophysicists to open an important new field of investigation into some of the most extremely unusual objects found in the universe. IXPE will examine polarized X-ray emissions from both galactic and extragalactic X-ray sources, such as active galactic nuclei, quasars, pulsars, pulsar wind nebulae, magnetars, accreting X-ray binaries, supernova remnants, and the Galactic Center. These observations will allow the investigation of general relativistic and quantum effects in the extreme environment associated with these sources and will significantly improve our understanding of fundamental physics. IXPE launched into a low Earth orbit at a low inclination angle for a two-year mission.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

IXPE completed its Key Decision Point-E review and successfully launched in December 2021. IXPE has completed a 21-day observation of the supernova remnant Cassiopeia A.

HELIOPHYSICS

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Heliophysics Research	280.8	216.1	**225.4**	224.7	226.2	226.0	226.0
Living with a Star	110.8	110.1	**137.3**	133.1	224.1	241.3	200.4
Solar Terrestrial Probes	133.3	234.3	**188.8**	199.1	117.5	77.2	61.4
Heliophysics Explorer Program	162.7	180.2	**157.9**	190.9	222.6	270.2	307.5
Space Weather	44.3	26.5	**22.3**	31.9	34.5	24.2	22.7
Heliophysics Technology	19.2	29.9	**28.4**	23.0	17.3	13.0	14.0
Total Budget	**751.0**	**797.2**	**760.2**	**802.6**	**842.0**	**851.9**	**831.9**

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Heliophysics

HELIOPHYSICS RESEARCH

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Heliophysics Research and Analysis	77.0	52.0	**53.5**	52.6	54.6	56.6	56.6
Sounding Rockets	73.6	62.6	**69.2**	69.2	69.2	69.2	69.2
Research Range	32.0	28.2	**26.9**	27.9	26.9	26.9	26.9
Other Missions and Data Analysis	98.2	73.4	**75.7**	75.0	75.5	73.3	73.3
Total Budget	**280.8**	**216.1**	**225.4**	**224.7**	**226.2**	**226.0**	**226.0**
Change from FY 2022 Budget Request			**9.3**				
Percent change from FY 2022 Budget Request			**4.3%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

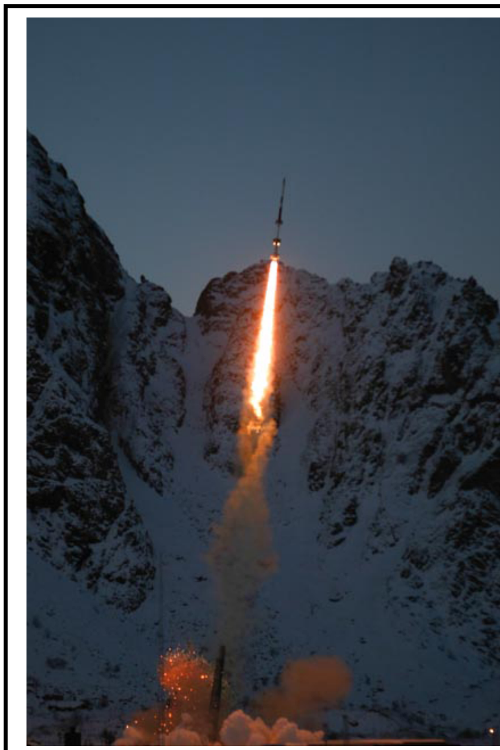
Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The Sun, a typical medium star midway through its life, governs the solar system. The Sun wields its influence through its gravity, radiation, solar wind, and magnetic fields, all of which spread out through the heliosphere, interacting with other planets, the Earth, and its space environments to produce space weather, which can affect human technological infrastructure and activities. Heliophysics seeks to understand the Sun, heliosphere, and planetary space environments as a single connected system to answer these fundamental questions:

- How and why does the Sun vary?
- How do Earth and the heliosphere respond to the Sun's changes?
- How do the Sun and the solar system interact with the interstellar medium?
- How do these processes affect human activities?

The Heliophysics Research program supports a wide variety of activities in support of these questions including:

- Investigations of the Sun, including processes taking place throughout the solar interior and atmosphere and the evolution and cyclic activity of the Sun;
- Investigations of the origin and behavior of the solar wind, energetic particles, and magnetic fields in the



Shown here is the Cusp Region Experiment 2 (CREX-2) launch from Andoya Space, Norway on December 1, 2021. The experiment aims to identify why there is a permanently denser region of air in the Earth's cusp-region thermosphere.

heliosphere and their interaction with Earth and other planets, as well as with the interstellar medium;

- Investigations of the physics of magnetospheres, including fundamental interactions of plasmas and particles with fields and waves, and coupling to the solar wind and ionospheres; and
- Investigations of the physics of the terrestrial mesosphere, thermosphere, ionosphere, including the coupling of these phenomena to the lower atmosphere and magnetosphere.

EXPLANATION OF MAJOR CHANGES IN FY 2023

Increases within the Sounding Rocket project enable the implementation of an astrophysics rocket campaign in Australia.

ACHIEVEMENTS IN FY 2021

In FY 2021, the Heliophysics Research program continued its increase in overall selections rates of Research Opportunities in Space and Earth Science (ROSES) proposals and implemented new and innovative elements around tool and model development, planning for the upcoming Decadal Survey and the Global Dynamics Constellation (GDC) mission, and interdisciplinary science. The program continued to enhance the scientific return of heliophysics research through an innovation to connect observations from one or more missions with satellite or ground observations from other divisions and/or other foreign and domestic agencies. In FY 2021, NASA released a solicitation for interdisciplinary science surrounding the 2021 total solar eclipse and a new due-date-free program element for one-year research projects that are not well suited for the larger existing programs.

The Voyager 2 spacecraft is currently operating in interstellar space. Recently, the spacecraft's Plasma Wave System detected perturbations in the interstellar gas. In between those eruptions – caused by our roiling Sun – researchers have uncovered a steady, persistent signature produced by the tenuous near-vacuum of space. Resembling a faint, monotone drone, this discovery allows researchers to measure the changing density of the Very Local Interstellar Medium, and that material's response to solar activity from the Sun. The Voyager spacecraft are the only platforms in interstellar space and are uniquely situated to make these measurements.

Researchers using Magnetospheric Multiscale (MMS) data discovered the new dayside source of energetic particles for Earth's radiation belts. This discovery demonstrated that local particle acceleration in magnetic field-free regions in the magnetosphere (diamagnetic cavities) can cause instabilities that lead to energetic electron microinjections, which can potentially form the source population of the hundreds of kiloelectronvolt particles to Earth's radiation belts. Previously, scientists had only considered the magnetotail reconnection to be responsible for this source of high energy particles.

NASA launched fifteen sounding rocket missions with campaigns in 2021. Due to COVID-19 safety concerns, the project predominately launched from United States ranges: Wallops Island in Virginia, and White Sands in New Mexico. The Sounding Rockets project began the year at White Sands Missile Range with the launch of DEUCE (Dual-channel Extreme Ultraviolet Continuum Experiment) in November of 2020.

In spring of 2021, the Spatial Heterodyne Interferometric Emission Line Dynamics Spectrometer, the Extreme Ultraviolet Normal-Incidence Spectrograph, and the Cosmic Infrared Background ExpeRiment launched from White Sands Missile Range for solar physics, solar wind, and astrophysics investigations. In May 2021, NASA launched the Kinetic-scale Energy and momentum Transport eXperiment from Wallops Island to study how momentum transport is affected by kinetic-scale physics, how electromagnetic energy is converted into plasma kinetic and thermal energy, and what the interplay is between fluid- and kinetic-scale processes. The range also saw the launch of the Very Low Frequency trans-Ionospheric Propagation Experiment Rocket, an observational and modeling effort to understand VLF wave penetration through, and propagation above, the Earth's ionosphere. In June 2021, Wallops Island saw the 13th flight of the hands-on, university-level rocket flight-training workshop known as "RockOn." RockOn is a collaborative effort between the Colorado Space Grant Consortium, the Virginia Space Grant Consortium, and Wallops Flight Facility.

Summer 2021 saw seven more launches from Wallops Island and White Sands Missile Range: the twin payloads of Dynamos, Winds, and Electric Fields in the Daytime Lower Ionosphere missions (Dynamo-2); the Marshall Grazing Incidence X-ray Spectrometer mission to determine the frequency of heating in active region cores on the Sun; SDO EVE Underflight Calibration Experiment calibrating the EVE instrument on the SDO spacecraft; and finally the RockSat-X student experiments, which were developed with an objective of providing students with an enhanced experience of flying experiments that are exposed to the space environment.

In addition, one CubeSat launched in September 2021, the Cusp Plasma Imaging Detector CubeSat, which seeks to answer longstanding questions regarding the macroscale properties of magnetic reconnection such as: what is the longitudinal extent of the reconnecting magnetopause; under what conditions do multiple reconnection sites form; and under what conditions is reconnection continuous versus in bursts? The process of magnetic reconnection changes magnetic topology and permits the flow of energy from the solar wind into the Earth's magnetosphere and ionosphere. This project has great relevance for goal number two of the Decadal Survey for Solar and Space Physics to "determine the dynamics and coupling of Earth's magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs."

Parker Solar Probe (PSP) completed orbits seven through nine during FY 2021, bringing the spacecraft within a record 6.5 million miles of the surface of the Sun. The PSP team meticulously meets its data delivery to the public data archives. Through enabling analysis of public PSP data, the Heliophysics research program added 43 PSP guest investigators through a competitive solicitation, which broadens the expertise of the science team to include members with expertise on dust, the space environment of Venus, and physics of turbulent plasmas.

The Solar and Heliospheric Observatory (SOHO), launched in 1995, continues to provide essential early alert space weather observations used as inputs to models that further our understanding of the Sun's effect on the Earth. Combined helioseismic data from the ground-based Global Oscillation Network Group, the MDI on board the SOHO spacecraft, and the Helioseismic and Magnetic Imager on board the Solar Dynamics Observatory, provided a unique opportunity to study how solar dynamics change with solar activity. These new data show, unambiguously, that there are solar-cycle related changes in the Sun deep within its interior.

The Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission continues to discover new aspects of magnetospheric waves and what drives the aurora. Researchers found when solar wind pulses strike, the waves that form not only race back and forth between Earth's magnetic poles and the front of the magnetosphere, but also travel against the solar wind and that surface waves at the edge of the plasmasphere can be correlated with Kelvin-Helmholtz waves. Additionally, new results from NASA's THEMIS-ARTEMIS spacecraft show that a type of Northern Lights called "diffuse auroras" comes from our own planet – no solar storms required. In a separate investigation, THEMIS observations in conjunction with the JAXA Arase mission showed electron acceleration 30,000 km above an auroral arc, a far greater distance for this process than previously expected.

WORK IN PROGRESS IN FY 2022

NASA will continue to fund projects competitively selected from Research Opportunities in Space and Earth Science (ROSES) 2021 and 2022. Notable new research solicitations include an extension of the DRIVE Center model with a Space Weather Center of Excellence, scientific studies of phenomena surrounding the 2024 total solar eclipse, and expanded data-readiness programs such as the Heliophysics Data Environment Enhancements and Heliophysics AI/ML Ready Data programs.

Phase one of the Heliophysics Diversify, Realize, Integrate, Venture, Educate (DRIVE) initiative as part of the integrated research program is coming to a close after two years of preliminary large-scale studies covering the breadth of Heliophysics science. Plans for a down-selection to two Centers (from eleven) will continue, in anticipation of an announcement of awards in Spring 2022.

The FY 2022 sounding rockets manifest features 17 NASA missions launching from various locations. Given the improvement in COVID-19 conditions and restrictions, several rocket launches are returning to non-US locations. Of note are the remote campaign flights, including the last of the US contributions to the Grand Challenge Cusp campaign (Norway/Andoya), a study of the equatorial sporadic E-layer observations, and three astrophysics launches from Australia.

NASA will continue to support the formulation and development of ten CubeSats. Science will continue to collaborate with the Exploration Systems Mission Directorate to enable the CubeSat mission to Understand Solar Particles over Earth's Poles on the first flight using the Space Launch System, Exploration Mission-1. Other CubeSat launches will include Daily Atmospheric Ionospheric Limb Imager, Low-Latitude Ionosphere/Thermosphere Enhancements in Density, Miniature X-ray Solar Spectrometer, and the Scintillation Prediction Observations Research Task, CubeSat: Inner Radiation Belt Experiment, Plasma Enhancements in The Ionosphere-Thermosphere Satellite, Relative Electron Atmospheric Loss, Geosynchronous Transfer Orbit Satellite, and CUbesat Radio Interferometry Experiment.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

In FY 2023, NASA will select new awards solicited in ROSES 2022, including continued research within Heliophysics' four main areas of inquiry - solar studies, magnetospheric studies, solar wind studies, and investigations of the uppermost regions of the Earth's atmosphere and how they interact with the space environment.

The Heliophysics Data Environment Enhancements element encompasses data environment needs throughout Heliophysics, including Solar, Heliospheric, Magnetosphere, and Ionosphere/Thermosphere/Mesosphere. The Heliophysics Research Program preferentially seeks to fund those efforts that directly impact NASA missions or interpretation of their data. However, the Program also includes projects involving data from other United States agencies or institutions judged to be highly beneficial to NASA Heliophysics research, if not available in a suitable form from their hosts institution. Plans for FY 2023 include the expansion of this element to include more data-readiness projects, as well as the development of community-generated data analysis tools.

The Heliophysics Artificial Intelligence/Machine Learning (AI/ML)-Ready Data element will solicit proposals that enable Heliophysics goals and objectives by developing new tools and methods for the generation of AI/ML-Ready datasets from existing research and mission data. The H-ARD element will create AI/ML-Ready datasets and products, which allow the use of AI/ML methodologies and approaches to address specific science problems.

In FY 2023 NASA will prepare for the 2024 solar eclipse via an Eclipse 2024 element within Research & Analysis. This element will support development of new research or enhancement of existing research, applied to the 2024 total solar eclipse visible from the northern hemisphere on April 8, 2024. This total solar eclipse will be visible from North America. This eclipse is the last total eclipse viewable from North America until August 2045. NASA is seeking proposals that would utilize the unique opportunity presented by the solar eclipse to study any relevant heliophysics research topic, such as a topic focused on the Sun or on the Ionosphere-Thermosphere-Mesosphere system.

The current sounding rockets mission manifest features 19 missions in FY 2023 from various locations in the United States, Norway, and Kwajalein Atoll.

Program Elements

RESEARCH RANGE

The Research Range project provides operations support, maintenance, and engineering for the WFF launch range in support of suborbital, orbital, and aircraft missions conducted on behalf of NASA and the Department of Defense. The project also supports NASA technology missions, autonomous aerial vehicle flights, and commercial launch and flight projects.

The range instrumentation includes meteorological, telemetry, radar, command, launch and range control centers, and optical systems. Research Range mobile assets provide range services at other ranges and remote locations around the world.

SOUNDING ROCKETS

NASA's Sounding Rockets project provides suborbital launch vehicles, payload development, and field operations support to NASA suborbital missions within the Science Mission Directorate. The approximately 20 suborbital missions flown annually by the project provide researchers with unparalleled opportunities to build, test, and fly new instrument and sensor design concepts while simultaneously conducting world class scientific research. Operations are conducted from fixed launch sites such as Wallops Test Range in Virginia, Poker Flat Research Range in Alaska, White Sands Missile Range in New Mexico, and foreign sites such as Andoya Rocket Range in Norway and Esrange in Sweden.

With the capability to fly higher than many low-Earth orbiting satellites and the ability to launch on demand, sounding rockets often offer the only means to study specific scientific phenomena of interest to many researchers. Unlike instruments on board most orbital spacecraft or in ground-based observatories, sounding rockets can place instruments directly into regions where and when the science is occurring to enable direct, in-situ measurements. The mobile nature of the project enables researchers to conduct missions from strategic vantage points worldwide. To study solar and astrophysics phenomena, telescopes and spectrometers fly on sounding rockets to collect unique science data and test prototype instruments for future satellite missions.

HELIOPHYSICS RESEARCH AND ANALYSIS

The Heliophysics Research and Analysis project supports basic research, solicited through NASA's annual Research Opportunities in Space and Earth Science (ROSES) announcements. It supports investigations in all research areas of Heliophysics: Sun, heliosphere, magnetosphere, ionosphere, and upper atmosphere. Investigations emphasize the understanding of fundamental processes and interconnections across the traditional science disciplines, on a broad range of spatial and temporal scales. The project also supports investigations focused on processes that create space weather events, and investigations to enable a capability for predicting future space weather events.

Heliophysics supporting research and theory, modeling, and simulation are essential in fully exploiting Heliophysics mission research data collected between the outer edge of the Earth's atmosphere and the interaction of the Sun and solar wind with the local galactic environment (currently explored by Voyager). The DRIVE science center element supports large principal-investigator proposed team efforts, which require a critical mass of interdisciplinary expertise, to make significant progress in understanding complex physical processes with broad importance. DRIVE centers employ a variety of fundamental research techniques (e.g., theory, numerical simulation, and modeling), analysis, and interpretation of space data.

Program Schedule

NASA implements the Heliophysics Research program via a competitive selection process. NASA releases research solicitations each year through the Research Opportunities in Space and Earth Science (ROSES) NASA Research Announcements (NRA).

Date	Significant Event
Q1 FY 2022	ROSES-2021 selection within six to nine months of receipt of proposals
Q2 FY 2022	ROSES-2022 solicitation
Q1 FY 2023	ROSES-2022 selection within six to nine months of receipt of proposals
Q2 FY 2023	ROSES-2023 solicitation
Q1 FY 2024	ROSES-2023 selection within six to nine months of receipt of proposals
Q2 FY 2024	ROSES-2024 solicitation
Q1 FY 2025	ROSES-2024 selection within six to nine months of receipt of proposals
Q2 FY 2025	ROSES-2025 solicitation

HELIOPHYSICS RESEARCH

Program Management & Commitments

Program Element	Provider
Research and Analysis	Provider: Headquarters (HQ) Lead Center: HQ Performing Centers: GSFC, MSFC, JPL, LaRC, JSC, ARC Cost Share Partners: None
Sounding Rockets	Provider: GSFC Lead Center: HQ Performing Center: GSFC Cost Share Partners: None
Research Range	Provider: GSFC Lead Center: HQ Performing Center: GSFC/WFF Cost Share Partners: None

Acquisition Strategy

NASA issues solicitations for competed research awards each February in the ROSES NRAs. To the widest extent possible, NASA fully and openly competes all new acquisitions. Proposals are peer-reviewed and selected from the annual ROSES announcement. Universities, Government research laboratories, and industry, throughout the United States, participate in research projects.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Sounding Rocket Operations	Orbital ATK	Dulles, VA

HELIOPHYSICS RESEARCH

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Relevance	Heliophysics Advisory Committee	2021	To review progress towards Heliophysics objectives in the NASA Strategic Plan	All areas were rated green in the Advisory Committee Report	2022
Relevance	Heliophysics Advisory Committee	2022	To review progress towards Heliophysics objectives in the NASA Strategic Plan	To be determined	2023
Relevance	Heliophysics Advisory Committee	2023	To review progress towards Heliophysics objectives in the NASA Strategic Plan	To be determined	2024
Quality	Mission Senior Review Panel	2023	A comparative evaluation of Heliophysics operating missions	To be determined	2026

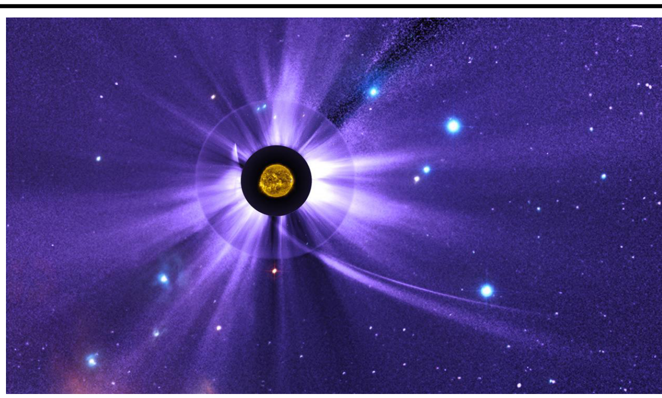
OTHER MISSIONS AND DATA ANALYSIS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Science Planning and Research Support	6.7	7.1	**7.1**	7.1	7.1	7.1	7.1
CubeSat	20.0	9.0	**9.0**	9.0	9.0	9.0	9.0
Solar Data Center	3.7	1.2	**1.2**	1.2	1.2	1.2	1.2
Data & Modeling Services	5.3	2.5	**3.0**	3.0	3.0	3.0	3.0
Space Physics Data Archive	2.3	2.3	**2.3**	2.3	2.3	2.3	2.3
Guest Investigator Program	32.1	23.0	**24.5**	24.5	24.5	24.5	24.5
Community Coordinated Modeling Center	4.6	4.9	**5.1**	5.4	5.6	5.6	5.6
Space Science Mission Ops Services	11.9	12.6	**13.5**	12.6	12.6	12.6	12.6
Voyager	6.5	5.6	**5.1**	5.0	5.2	5.2	5.2
SOHO	2.3	2.4	**2.2**	2.2	2.2	0.1	0.0
Wind	2.2	2.2	**2.3**	2.3	2.3	2.3	2.3
Geotail	0.5	0.6	**0.5**	0.5	0.5	0.5	0.5
Total Budget	**98.2**	**73.4**	**75.7**	**75.0**	**75.5**	**73.3**	**73.3**
Change from FY 2022 Budget Request			**2.3**				
Percent change from FY 2022 Budget Request			**3.1%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



SOHO, SDO, and many other missions observe the Sun and spot comets as they pass by. In this image, Comet ISON swoops around the Sun and through Scorpius. This composite picture merges an SDO image, several SOHO images, and a DSS view of the sky in northern Scorpius.

NASA accumulates, archives, and distributes data collected by the Heliophysics System Observatory, a fleet of operating spacecraft. Combining the measurements from all these observing platforms enables interdisciplinary, connected systems science across the vast spatial scales of our solar system. This collective asset enables the data, expertise, and research results to contribute directly to fundamental research on solar and space plasma physics and to the national goal of real-time space weather prediction. NASA teams support day-to-day mission operations for NASA spacecraft and data analysis to advance the state of space science and space weather modeling. NASA conducts science community-based projects to evaluate research models containing space weather information that is of value to industry and Government agencies. Heliophysics data centers archive and

OTHER MISSIONS AND DATA ANALYSIS

distribute the science data from operating missions in the Living With a Star (LWS), Solar Terrestrial Probes (STP) Research, and Explorer Programs.

Mission Planning and Other Projects

SCIENCE PLANNING AND RESEARCH SUPPORT

This project supports NASA scientists' participation in proposal peer review panels, decadal surveys, and National Academies' studies.

CUBESAT

CubeSats are small spacecraft, built to a standardized form-factor of size and mass, which can launch as secondary or ride-share payloads. With lower development costs per investigation and rapid development cycles, CubeSats can provide frequent science and technology flight opportunities. This approach is like the traditional NASA suborbital programs that use sounding rockets, balloons, and aircraft, but extends the range of opportunities. CubeSats have significant potential to leverage exploratory and systematic science observations at minimal additional cost.

The Heliophysics CubeSat project continues to work on the cross-discipline investigations already underway. In response to the capabilities demonstrated by CubeSat investigations in the initial pathfinder stage, the CubeSat project expanded in 2019 to take advantage of new science achievable via investigations in the $2 million to $10 million range. The Heliophysics CubeSat project has three projects on orbit with an additional nineteen waiting for flight, and ten planned for launch in 2022. The project added an additional two projects in FY 2021, and an additional three projects in FY 2022. The larger investigations will enable the development of remote sensing investigations with more sophisticated CubeSats, as well as small constellations of in-situ CubeSat investigations.

Recent Achievements

The Cusp Plasma Imaging Detector (CuPID) CubeSat launched in September 2021 and will aim to answer longstanding questions regarding the macroscale properties of magnetic reconnection. The CubeSat project also continued to support the formulation and development of the ten CubeSats planned for launch in 2022.

SOLAR DATA CENTER

The Solar Data Center (SDAC) provides mission and instrument expertise to enable high-quality analysis of solar physics mission data. It provides leadership for community-based, distributed development efforts to facilitate identification of and access to solar physics data, including ground-based coordinated observations via the Virtual Solar Observatory, a research tool that allows scientists to search for solar and heliospheric physics data. The SDAC also provides a repository for software used to analyze these data.

Recent Achievements

The SDAC has generated datasets from Parker Solar Probe, Focusing Optics X-ray Solar Imager (FOXSI, a sounding rocket), Miniature X-ray Solar Spectrometer (MinXSS, a CubeSat), Sunrise (balloon-based

OTHER MISSIONS AND DATA ANALYSIS

observatory) and made them available via the Virtual Solar Observatory. To store these datasets and additional upcoming data, the Solar Data Center expanded on-site storage by approximately one petabyte. The SDAC also supports tool development to access the datasets, and enlarged the Helioviewer programming team to support a pilot program running Helioviewer on Amazon Web Services (AWS)

DATA AND MODELING SERVICES

The Data and Modeling Services project supports missions in extended operations and missions planned for decommissioning, by preparing their data holdings for long-term archival curation. This project also provides for the creation of higher-level data products, which are of significant use to the science community and not funded during the prime mission. Higher-level data products are data that combine results of multiple missions and/or instruments. Elements of this project are competed through the annual ROSES competitive announcement.

Recent Achievements

The Heliophysics Data and Modeling group began strengthening data usability and accessibility by working with the NASA Astronomical Data System (ADS) and the Goddard Space Flight Center (GSFC) Center for Helio-Analytics (CfHA) to build an advanced Discovery search service, which will aid researchers in finding datasets that are most relevant to a given phenomenon type. The Data and Modeling group also conducted outreach and planning meetings to better integrate and enhance the Python in Heliophysics Community (PyHC), thereby providing more analytic tools to the research community. In addition, they also initiated work on building a community heliophysics cloud computing resource that aims to provide heliophysicists with fundamentally new and easily used computing capabilities that will employ datasets of unprecedented size and complexity to advance the field of heliophysics science.

SPACE PHYSICS DATA ARCHIVE

The Space Physics Data Archive (SPDA) ensures long-term data preservation and online access to non-solar heliophysics science data. It operates key infrastructure components for the Heliophysics Data Environment, including inventory and web service interfaces to systems and data. It also provides unique enabling science data services.

The Heliophysics data archives are growing at an exponential rate. All science disciplines have seen a surge of data holdings over the last decade. As such, conventional storage and retrieval has become impractical. This era of Big Data requires the effective curation and preservation of critical data products. NASA will move beyond a traditional repository and toward a functional, collaborative data library. Over the next several years, NASA will transform the Heliophysics archives, consisting of the SPDC and SDAC, into a digital resource library.

Recent Achievements

The SPDA has added more than 470 data sets from current and historic missions, along with sounding rocket, balloon, and ground instrument datasets. To support these missions, Space Physics Data Facility (SPDF) maintains an automated data ingest pipeline for more than 75 missions, with an average monthly data ingestion rate of 0.6 million files, or approximately twelve terabytes of data. In addition to data ingest, legacy mission datasets must be reprocessed and often placed into the proper formats. NASA created reformatted files for Solar and Heliospheric Observatory in-situ data and Wind SupraThermal Ion Composition Spectrometer (STICS) instrument data. The SPDA team continued populating and updating

OTHER MISSIONS AND DATA ANALYSIS

several databases of solar wind conditions and geomagnetic activity indices; deep space merged magnetic field, plasma, proton fluxes and ephemerides data; and spacecraft orbit information. The SPDA also supported tool development to access and manipulate these datasets and completed improvements to the Coordinated Data Analysis (CDA)Web plot and display system.

GUEST INVESTIGATOR PROGRAM

The Guest Investigator Program maximizes the output of currently operating Heliophysics missions by supporting competitive research investigations, which use data from multiple spacecraft. The Heliophysics division strongly encourages investigations that address global system science since Heliophysics, by nature, is the investigation of a large-scale and complex connected system.

Recent Achievements

The Heliophysics Guest Investigator scientific review panels utilized the Dual Anonymous Peer Review (DAPR) process in the most recent solicitation. The DAPR process means that reviewers on scientific panels do not know the names or affiliation of the proposed research efforts when reviewing and evaluating proposals. Thus, the merits of proposed work are the primary focus of the review panel's evaluation. In the first year of DAPR implementation not only was there an increase in submission rate of early career scientists, but there was also an increase in the success rate of early career scientists from 35.5 percent without DAPR to 46.7 percent with DAPR.

One recently funded research effort examined and characterized the statistical features of magnetic dips found within the inner magnetosphere. Researchers initially reported on a magnetic dip driven by the enhancement of suprathermal proton pressure with larger magnetic depth and wider spatial scale. Embedded within the magnetosphere was a smaller magnetic dip driven by electron pressures, which exhibit spatial separation and cannot be ignored when examining the phenomena in detail. Moreover, the relativistic and ultra-relativistic electron fluxes over different energies manifest as multiple echoes of the butterfly pitch-angle distribution, which is the first reporting of this observation.

COMMUNITY COORDINATED MODELING CENTER

The Community Coordinated Modeling Center (CCMC) is a multi-agency partnership that enables and performs the research and development for next-generation heliophysics and space weather models. The project provides the United States and international research community access to simulations that enable “runs on demand,” using models to study space weather events in near-real time. This allows the comparison of observational data and model parameters during or shortly after solar activity, thereby improving accuracy of the models.

Recent Achievements

The Integrated Solar Energetic Proton (ISEP) Event Alert/Warning System represents a collaboration between the Space Radiation Analysis Group (SRAG) and CCMC to bring state-of-the-art space weather models from research and development at universities and small businesses to operational use as a Research to Operations effort. The goal of ISEP is to provide mitigation of crew radiation exposure due to large solar particle events. The culmination of this partnership created a Solar Energetic Proton Scorecard, which is a beta online web application that the CCMC team continues to update with ISEP scripts, forecast models, and associated documentation. This tool will allow the SRAG console operator to review models of space weather data and formulate the best crew response to changes in the space weather environment.

SPACE SCIENCE MISSION OPERATIONS SERVICES

Space Science Mission Operations (SSMO) Services manages the on-orbit operations of GSFC Space Science missions. Services include consistent processes and infrastructure for missions operated at various institutions. SSMO currently manages the following missions: Advanced Composition Explorer (ACE), Aeronomy of Ice in the Mesosphere (AIM), Geotail, Interstellar Boundary Explorer (IBEX), Ionospheric Connection Explorer (ICON), Interface Region Imaging Spectrograph (IRIS), Magnetospheric Multiscale Mission (MMS), Parker Solar Probe, Solar Dynamics Observatory (SDO), Solar and Heliospheric Observatory (SOHO), Solar Terrestrial Relations Observatory (STEREO), THEMIS, Thermosphere Ionosphere. Mesosphere Energetics and Dynamics (TIMED), and Wind. SSMO Services also sustains an operational multi-mission infrastructure for current and future missions.

Recent Achievements

Space Science Mission Operations has continued its support and enhancement for operational heliophysics missions managed at GSFC. This includes responding to the shifting needs of IT security driven demands to protect and maintain legacy missions, ongoing conjunction analysis to avoid satellite collisions, and enhancements to operational tools to improve situational awareness and access to spacecraft telemetry. Accomplishments include adoption of continuous diagnostic and monitoring tools to provide insight and management of IT security vulnerabilities, expansion of the virtualized Multi-Mission Operations Center (vMMOC) hardware platform enabling improved flexibility for ground system build and updates, enhancement of integrated flight dynamics operations capabilities, and expansion of ground system middleware tools.

Operating Missions

VOYAGER

The Voyager Interstellar Mission is exploring the interaction of the heliosphere and the local interstellar medium. Voyager 1, launched in 1977, is making the first in-situ observations of the region outside the heliosphere from about 156 astronomical units (AU), or 156 times Earth’s distance from the Sun, and is traveling at a speed of 3.6 AU per year, or 38,000 miles per hour. Voyager 2 is about 130 AU from the Sun and traveling at a speed of about 3.2 AU per year. Voyager 2 crossed the heliopause, the theoretical boundary where the Sun's solar wind is stopped by the interstellar medium, on November 5, 2018. Its twin, Voyager 1, crossed the heliopause on August 25, 2012, and continues to sail outward through the local interstellar medium. Both spacecraft have sufficient power to operate all instruments until the early 2020s; after this time, the project will turn off the instrument heaters and then the instruments one at a time to extend the useful life of the spacecraft to about 2030. Voyager is currently in extended operations.

Recent Achievements

In 2012, Voyager 1 became the first in situ probe of the very local interstellar medium (VLISM). The Voyager 1 Plasma Wave Science (PWS) instrument is the only current instrument that can make in situ measurements of the plasma density in the VLISM. PWS has provided point estimates of the plasma

OTHER MISSIONS AND DATA ANALYSIS

density spanning about 30 AU of interstellar space, revealing large-scale changes in density, as well as turbulence outside of the heliopause.

Recently, Voyager Science Team members discovered that they could measure plasma density continuously from subtle oscillations of the VLISM plasma. This discovery opens new possibilities for studying the plasma density in the VLISM. Specifically, it can reveal plasma density waves originating from energetic events at the Sun, as well as the fine-scale turbulent structure of the interstellar plasma.

Possible mechanisms for this newly detected emission include thermally excited plasma oscillations from heated plasma, and they could be clarified by new findings from Voyager or a future interstellar mission. The emission's persistence suggests that Voyager 1 may be able to continue tracking the interstellar plasma density in the absence of shock-generated plasma oscillation events. The thermally driven plasma oscillations provide evidence of this density compression in the interstellar plasma.

SOLAR AND HELIOSPHERIC OBSERVATORY (SOHO)

SOHO, launched in 1995, is a joint mission of the European Space Agency (ESA) and NASA, and it has been a dependable solar watchdog, providing the only Earth-Sun line coronagraph images of solar storms. Coronal mass ejections (CME) drive most of the space weather effects in the inner heliosphere. SOHO continues to provide essential early alert space weather observations used as inputs to models that further our understanding of the Sun's effect on the Earth. During its extended mission phase, NASA declared SOHO a national space weather asset and the mission will participate in a programmatic review (outside of the Senior Review) in 2023.

Recent Achievements

Combined helioseismic data from the ground-based Ground Oscillation Network Group (GONG), the Michelson Doppler Imager (MDI) on board the Solar and Heliospheric Observatory spacecraft, and the Helioseismic and Magnetic Imager on board the Solar Dynamics Observatory provided a unique opportunity to study how solar dynamics changes with solar activity. As the helioseismic data spanning two solar cycles (23 and 24) became available, scientists have redone the analysis using improved analysis techniques to determine whether there are changes inside the Sun at depths corresponding to where helium is ionized. This was done by measuring the amplitude of the signature of the acoustic glitch caused by the second ionization of helium. They found that the amplitude of the glitch changes with time and that it is anti-correlated with solar activity. This behavior is seen in both ground-based and space-based data. This shows, unambiguously, that there are solar-cycle related changes in the Sun at depths even below 0.9 of Solar Radius.

The Solar Wind ANisotropies (SWAN) camera on the SOHO spacecraft, located in a halo orbit around the Earth–Sun L1 Lagrange point, makes daily full-sky images of hydrogen Lymen-alpha (Lyα) and performed observations of C/2020 F3 (NEOWISE) comet. The Near-Earth Object program of the Wide-Field Infrared Survey Explorer (NEOWISE) originally discovered this comet and helped it become the Great Comet of 2020. Researchers determined water production rates using the SWAN hydrogen Lyα brightness and spatial distribution of the comet measured over a 4-month period on either side of the comet's perihelion on July 3, 2020.

OTHER MISSIONS AND DATA ANALYSIS

WIND

Wind, launched in 1994, studies the solar wind and its impact on the near-Earth environment. It provides comprehensive measurements of thermal to solar energetic particles, quasi-static fields to high-frequency radio waves, and gamma rays. In particular, the Wind instrument suite provides comprehensive and unique high-time resolution in-situ solar wind measurements that enable the investigation of wave-particle interactions. Wind provides critical measurements of the solar wind and space weather events. Correlating those critical measurements with measurements from the Parker Solar Probe and Solar Orbiter Collaboration (SOC) missions will improve our understanding of these events as they move out from the Sun. These multi-spacecraft measurements constrain models of space weather events and improve their predictive capabilities. Wind is also the only near-Earth spacecraft equipped with radio waves instrumentation. The Radio and Plasma Wave (WAVES) experiment measures electric and magnetic fields to reveal wave phenomena in the solar wind. WAVES is also the only instrument on Wind that can unambiguously measure the total electron density in the solar wind. No other L1 spacecraft has this capacity, which allows Wind to more accurately calibrate all of its thermal particle instruments. Currently in extended operations, NASA approved Wind to continue as HSO-Infrastructure at the 2020 Heliophysics Senior Review. Wind will participate in programmatic review (outside Senior Review) in 2023.

Recent Achievements

Fast radio bursts, or FRBs, are bright flashes of radio energy, which last just milliseconds and originate outside our galaxy. Presently, more than one hundred FRBs are known, and more are being discovered that flash repeatedly. Highly magnetized young neutron stars, known as magnetars, have emerged as leading candidates for the source of FRBs. However, until recently, there has been no observational evidence directly linking FRBs with magnetars or any other astrophysical phenomena. On April 28, 2020, several space detectors, including the Russian Konus-Wind instrument operating aboard the NASA Wind spacecraft, as well as radio telescopes on the Earth's surface, detected simultaneous X-ray and radio bursts similar to FRBs from the Galactic magnetar known as SGR 1935+2154. Although the energy of the x-ray/radio burst and extragalactic FRBs are different by several orders of magnitude, this discovery provides new evidence that magnetars could be the source of extragalactic FRBs.

GEOTAIL

Geotail, launched in 1992, enables scientists to assess data on the interaction of the solar wind and magnetosphere. Its instruments continue to function, sending back crucial information about how auroras form, how energy from the Sun funnels through near-Earth space, and the ways in which magnetic field lines move and rebound, creating explosive bursts that rearrange the very shape of our magnetic environment. The Geotail mission is a collaborative project undertaken by the Japanese Institute of Space and Astronautical Science and NASA. Although currently in extended operations, NASA approved Geotail to continue as HSO-Infrastructure at the 2020 Heliophysics Senior Review. Geotail will participate in a programmatic review (outside Senior Review) in 2023.

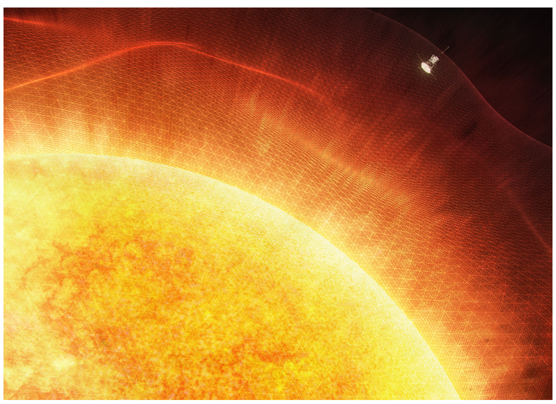
LIVING WITH A STAR

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Other Missions and Data Analysis	110.8	110.1	**137.3**	133.1	224.1	241.3	200.4
Total Budget	**110.8**	**110.1**	**137.3**	**133.1**	**224.1**	**241.3**	**200.4**
Change from FY 2022 Budget Request			**27.2**				
Percent change from FY 2022 Budget Request			**24.7%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



For the first time in history, a spacecraft has touched the Sun. NASA's Parker Solar Probe has now flown through the Sun's upper atmosphere – the corona – and sampled particles and magnetic fields there, as shown above.

The Living With a Star (LWS) Program targets specific aspects of the Sun-Earth system that affect life and society. LWS provides a predictive understanding of the Sun-Earth system, linkages among the interconnected systems, and space weather conditions at Earth and the interplanetary medium. Measurements and research from LWS missions may contribute to advances in operational space weather forecasting that help prevent damage to spacecraft, communications and navigation systems, and power grids. LWS products improve our understanding of ionizing radiation, which has human health implications on the ISS and high-altitude aircraft flight, as well as operations of future space exploration with and without human presence. LWS products improve the characterization of solar radiation for global climate change, surface warming, and ozone depletion and recovery.

EXPLANATION OF MAJOR CHANGES IN FY 2023

Both the Heliophysics Environmental and Radiation Measurement Experiment Suite (HERMES) and Space Weather Science & Applications projects now reside within the newly created Space Weather Program.

The budget includes $5 million for a new Orbital Debris & Space Situational Awareness (OD-SSA) initiative within the LWS Program. This initiative will address a knowledge gap of near-Earth space by focusing on orbital objects of both natural and anthropogenic sources that cannot be directly characterized by ground measurements.

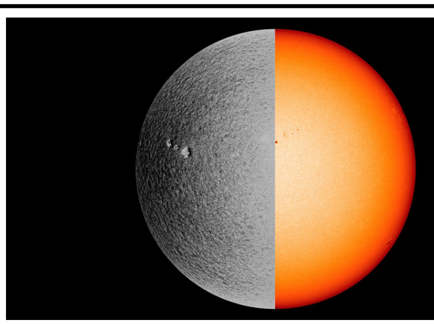
OTHER MISSIONS AND DATA ANALYSIS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Geospace Dynamics Constellation	16.0	23.3	**63.0**	49.4	132.9	151.6	103.0
Living With a Star Future Missions	0.0	3.3	**5.0**	5.0	5.0	5.0	12.5
Solar Orbiter Collaboration	10.1	8.2	**4.7**	4.7	8.2	8.3	8.3
LWS Space Environment Testbeds	0.4	0.0	**0.0**	0.0	0.0	0.0	0.0
LWS Science	30.3	30.3	**19.3**	30.3	30.3	30.3	30.3
LWS Program Management	33.6	21.6	**21.4**	20.0	20.7	21.7	24.5
Solar Dynamics Observatory (SDO)	13.4	16.1	**12.8**	12.3	12.3	12.3	12.3
Parker Solar Probe	7.0	7.4	**11.1**	11.3	14.6	12.1	9.5
Total Budget	**110.8**	**110.1**	**137.3**	**133.1**	**224.1**	**241.3**	**200.4**
Change from FY 2022 Budget Request			**27.2**				
Percent change from FY 2022 Budget Request			**24.7%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



Images from space reveal the chaotic motions on the Sun's surface layer, the photosphere. Since 2010, the Helioseismic and Magnetic Imager (HMI) instrument aboard NASA's Solar Dynamics Observatory (SDO) spacecraft has observed oscillating solar material on the photosphere. Shown above, the left side of the sphere is an HMI image in which dark and light areas represent vibrations on the Sun's surface produced by pressure waves. The right side shows an SDO image of the photosphere.

Living With a Star (LWS) Other Missions and Data Analysis budget includes operating LWS missions, scientific research, program management, and funding for missions to launch in the next decade.

Mission Planning and Other Projects

LWS SCIENCE

NASA solicits proposals leading to a physics-based understanding of the integral system linking the Sun to the Earth, both directly and via the heliosphere, magnetosphere, and ionosphere. LWS Science objectives can be achieved by data analysis, theory and modeling, and the development of tools and methods (e.g., software). The goal of the project is to develop the scientific understanding needed for the United States to address those aspects of heliophysics that may affect life and society. The targeted research element solicits large-scale problems that cross discipline and technique boundaries.

In addition, LWS Science includes funding to train the next generation of heliophysics experts, conduct a heliophysics

OTHER MISSIONS AND DATA ANALYSIS

graduate-level summer school, develop graduate course content, and support a limited number of space weather postdoctoral positions at universities and Government laboratories.

Recent Achievements

In FY 2021, scientists working on the role of magnetic topology in determining the occurrence of solar flares have examined the geometry, connectivity, and topology of the large-scale solar magnetic fields, the role they play in magnetic reconnection, and how this results in a solar flare. This study involves a large sample of flaring active regions with both eruptive and non-eruptive events, as well as several robust models of the solar magnetic field. Current results show relatively small differences between observations and model simulations, particularly in the polarity of the magnetic field and the spread in the predicted wind speed, which will lead to improvement in the prediction of flares.

Several research teams are examining processing in the Earth's ionosphere. One team is quantifying the variability of equatorial electrodynamics during geomagnetic storms and using models to examine the variability in the equatorial electrodynamics during geomagnetic disturbed periods. Numerical simulations have revealed the storm-time changes in the ionosphere-thermosphere system that contribute to the variability of equatorial electrodynamics. Their recent studies evaluated model performance during a solar storm and show that high-resolution modeling provides much higher cross-polar-cap potential, as well as simulated ion drifts that capture the zonal flows shown in the satellite observations. Another research team is studying storm time changes in the ionosphere-thermosphere system, specifically the longitudinal variability in the ionospheric density from equatorial to mid latitudes and the associated changes in the neutral and ionospheric dynamics produced by geomagnetic storms. Their findings include improved understanding of the dawn and post-dawn plasma bubbles, likely triggered during the recovery phase of the magnetic storm, and the relationship between strong ionospheric scintillation and electron density minima after sunrise. Results from both teams improve our understanding of ionosphere dynamics.

In addition, a team that is modeling the causes and consequences of solar eruptive events that drive major coronal mass ejections (CMEs) has recently examined streamer-blowout, or stealth, CMEs observed by the Parker Solar Probe (PSP) at 0.5 Astronomical units (AU). Stealth CMEs are eruptions that cannot be linked to a well-defined source region on the Sun. Analysis of their source is problematic, as is the prediction of these events and their impact on space weather events. By examining data from PSP as well as ultraviolet (UV) observations from the STEREO-A spacecraft (off the Earth-Sun line) and photospheric magnetic field observations from SDO/HMI, they are able to estimate the source region of these events, thus increasing the predictability of this type of CME.

LWS PROGRAM MANAGEMENT

The Program Management budget supports critical flight project management functions executed by the LWS program office at NASA Goddard Space Flight Center (GSFC) and provides the resources required to manage the planning, formulation, and implementation of all LWS missions. Included in LWS Program Management is the Science Mission Directorate Rideshare Office. This office implements an SMD-wide rideshare strategy for Evolved Expendable Secondary Payload Adapter-class (ESPA-class) payload opportunities. The office is responsible for coordinating rideshare opportunities and collaborating across SMD, other NASA science directorates, other Government agencies, and the greater rideshare community to foster a culture of cross-collaboration and maximize science return through shared launch opportunities and resources.

OTHER MISSIONS AND DATA ANALYSIS

LWS FUTURE MISSIONS

The Future Missions budget supports pre-formulation activities related to the identification of LWS science and mission objectives and priorities. This project also supports activities related to Orbital Debris & Space Situational Awareness (OD-SSA).

Orbital debris at all scales is present in the space environment, which affects space-based critical infrastructure, modern technological systems, and humans working in space. The NASA OD-SSA activity will address a knowledge gap of this environment by focusing on orbital objects of both natural and anthropogenic sources that cannot be directly characterized by ground measurements, typically below 3cm in size and all the way to nanometer-sized dust.

The NASA OD-SSA activity will involve a diverse mixture of elements including competed research, directed and competed flight components, and interagency and international cooperation. This approach allows the activity to address gaps in orbital objects and serves to enable the efficient maturation of technologies and subsequent transfer of critical new capabilities to partner agencies such as DOC, NOAA, and the DoD. Activities in FY 2023 will include the development and laboratory testing of multiple OD sensor concepts and the preparation of a prototype OD sensor that will be delivered for integration into the DoD Space Test Program (STP) STPSat-7 satellite, as well as the selection of awards for the development of new OD/dusts sensors.

GEOSPACE DYNAMICS CONSTELLATION

Geospace Dynamics Constellation (GDC) will be the first mission to conduct a coordinated, global study of Earth's upper atmosphere, the heart of Earth’s space environment. The upper atmosphere is a dynamic region of overlapping neutral atmosphere and ionosphere, where processes are driven by mass and energy inputs from both below (Earth's lower/middle atmosphere) and above (Earth's magnetosphere and the Sun). These inputs from above and the dynamics active within the upper atmosphere include space weather processes that impact the human presence and technological assets in space.

GDC will be the first mission to address this science on a global scale due to its use of a constellation of spacecraft that permit simultaneous multi-point observations. The relative spacing between the individual spacecraft of the GDC constellation will evolve over the course of the mission, fully sampling the spatial and temporal scales necessary to provide complete scientific understanding of this region and various space weather phenomena.

The 2013 Heliophysics Decadal Survey recommended the GDC mission concept. The Science and Technology Definition Team (STDT) has refined and updated the decadal mission concept. Subsequently, NASA initiated mission formulation activities and directed project management to GSFC. The GDC estimated launch date is no earlier than September 2027.

Recent Achievements

NASA initiated a competition for GDC investigations in FY 2021. NASA released the solicitation in June 2021, received proposals in September 2021, and anticipates announcing selections in Spring 2022. Selected investigation teams will deliver instruments for integration on the GDC spacecraft and will join the GDC science team.

NASA released a solicitation for GDC Interdisciplinary Scientists (IDSs) in March 2021, received proposals in June 2021, and announced selections in November 2021. The IDSs are scientists that will

OTHER MISSIONS AND DATA ANALYSIS

join the mission science team separately from the GDC investigation selections. Their activities focus on those recommended by the GDC STDT that are outside of the individual investigation teams' responsibilities, including but not limited to developing necessary modeling capabilities and identifying potential ground-based observations to support GDC science operations. Among the tasks that the selected IDSs will execute are the development of a visualization tool to understand and optimize the constellation configuration, and the development of a process to leverage the spacecraft navigation data to independently measure the local atmospheric density.

NASA completed funded spacecraft studies in September 2021, conducted by commercial companies with the proven ability to provide spacecrafts appropriate for the GDC mission.

Operating Missions

SOLAR ORBITER COLLABORATION

The NASA and European Space Agency (ESA) Solar Orbiter Collaboration (SOC) mission provides measurements that will give NASA better insight on the evolution of sunspots, active regions, coronal holes, and other solar features and phenomena. The instruments explore the near-Sun environment to improve our understanding of the origins of the solar wind streams and the heliospheric magnetic field; the sources, acceleration mechanisms, and transport processes of solar energetic particles; and the evolution of CMEs in the inner heliosphere. To achieve these objectives, SOC makes in-situ measurements of the solar wind plasma, fields, waves, and energetic particles. SOC also makes imaging/spectroscopic observations. SOC provides close-up views of the Sun’s polar- regions and far side. SOC adjusts its orbit to the direction of the Sun’s rotation to allow the spacecraft to observe one specific area for much longer than is currently possible. The prime mission will continue until May 2027.

ESA provided the spacecraft and manages operations. The ESA member states provided most of the instruments. NASA provided the launch vehicle and two science investigations/instruments: The Solar Orbiter Heliospheric Imager (SoloHI) and the Heavy Ion Sensor (HIS). In return for its contributions, NASA will have access to the entire science mission data set.

Recent Achievements

Solar Orbiter launched in February 2020 and is in the operational phase. HIS/Solar Wind Analyzer performed commissioning activities and began data acquisition in April 2021. HIS collected observations of the solar wind interaction with the magnetosphere of Venus during Solar Orbiter’s second Venus Gravity Assist Maneuver in August 2021. SoloHI observed its first CME on February 12, 2021. This event was also observed from multiple viewpoints by instruments on the SOHO, STEREO, and ESA Proba-2 missions. SoloHI also obtained unprecedented images of Venus as Solar Orbiter’s flew within 5,000 miles (8,000 km) from the surface of the planet in August 2021.

SIS/EPD has measured heavy ion intensity spectra as a function of energy in the inner heliosphere during several solar particle events and has also obtained quiet-time spectra of energetic ions in the solar wind. SIS also observed energetic ions in the unique magnetic environment around Venus during Solar Orbiter’s first pass of the planet in December 2020, leading to new understanding of particle acceleration processes in the Venusian system.

OTHER MISSIONS AND DATA ANALYSIS

PARKER SOLAR PROBE

Parker Solar Probe (PSP), launched in 2018, is unlocking the mysteries of the Sun's atmosphere. Parker Solar Probe has flown through the solar corona 9 out of an expected 24 times, gradually lowering its orbit closer to the Sun using Venus' gravity during seven flybys over its seven-year mission with prime missions ending in 2024. After the seventh Venus flyby, the spacecraft flew though the Sun's atmosphere as close as 3.8 million miles to our star's surface - well within the orbit of Mercury and more than seven times closer than any spacecraft has come before. Earth's average distance to the Sun is 93 million miles.

Flying into the outermost part of the Sun's atmosphere, the corona, for the first time, PSP employs a combination of in-situ measurements and imaging to revolutionize our understanding of the corona and expand our knowledge of the origin and evolution of the solar wind. PSP will also make critical contributions to our ability to forecast changes in Earth's space environment that affect life and technology on Earth.

Recent Achievements

In 2021, PSP "touched the Sun," meaning the spacecraft has passed through the Sun's Alfvén point, which is the region around the Sun where the solar wind reaches supersonic outflow speed. PSP also successfully completed solar encounters seven, eight, and nine. Both the 8th and 9th perihelia (closest approaches to the Sun) achieved record-breaking distances at 6.5 million miles off the Sun's surface, or 14 times closer than the Earth from the Sun, and record-breaking speeds of about 330,000 miles per hour. Fifteen additional solar approaches are planned, with the last three bringing the probe to as close as approximately four percent of the Earth's distance from the Sun in 2024.

PSP discovered a novel process and type of dust near the Sun. Using data from Parker Solar Probe, researchers saw dust impacts that were consistent with the two primary dust populations in the zodiacal dust cloud. The first population are grains being slowly pulled toward the Sun over thousands to millions of years; then, as the swirling cloud gets denser, the larger grains collide and create fragments called beta-meteoroids that are pushed out of the solar system in all directions by pressure from sunlight. PSP picked up an enhancement in dust detections that didn't match the two-component model, a tip that another dust population may be in the area. The researchers theorized that a meteoroid stream - most likely the Geminids stream, which causes one of the most intense meteor showers at Earth - was colliding at high speeds into the inner zodiacal cloud itself. These impacts with zodiacal dust produce beta-meteoroids that don't blast off in random directions but are focused into a narrow set of paths that intersect with PSP's outbound orbit.

The Parker Solar Probe team has earned the National Space Club and Foundation's Nelson P. Jackson Aerospace Award for its efforts to untangle the long-standing mysteries of the complex solar environment, which recognizes the most outstanding contribution to aerospace in the preceding year.

SOLAR DYNAMICS OBSERVATORY (SDO)

Launched on February 11, 2010, SDO seeks to understand the Sun's influence on Earth and near-Earth space by simultaneously studying the solar atmosphere on small scales of space and time and in many wavelengths. The observatory enables scientists to determine how the Sun's magnetic field is generated and structured and how stored magnetic energy is converted and released in the form of solar wind, energetic particles, and variations in the solar irradiance. SDO collects data to help explain the creation of solar activity, which drives space weather. Measurements of the interior of the Sun, the Sun's magnetic

OTHER MISSIONS AND DATA ANALYSIS

field, the hot plasma of the solar corona, and the irradiance that creates Earth's ionosphere are the primary data products. SDO will participate the 2023 Heliophysics Senior Review to determine future extended mission operations.

Recent Achievements

NASA's images of the Sun's dynamic and dazzling beauty have captivated the attention of millions. In 2021, the United States Postal Service issued a set of stamps highlighting views of the Sun from NASA's Solar Dynamics Observatory. Showcasing a range of solar activity seen by the spacecraft, the stamps celebrate a decade of Sun-watching for this workhorse mission.

Data from SDO continues to be extremely valuable to the science community and has allowed for collaborative research work with an international team that was published in Astronomy & Astrophysics, in April of 2021. The research focuses on the time-dependent degradation of instruments that reduces their sensitivity. Current best calibration techniques rely on flights of sounding rockets to maintain absolute calibration. These flights are infrequent, complex, and limited to a single vantage point. A team of researchers supported by LWS developed a novel method based on machine learning (ML) that exploits spatial patterns on the solar surface across multiwavelength observations to auto-calibrate the instrument degradation. The results indicate that the ML-based models significantly outperform the non-ML baseline model in calibrating instrument degradation. This approach establishes the framework for a novel technique based on ML to calibrate Extreme-UV (EUV) wavelength instruments. This technique has the potential to be adapted to other imaging or spectral instruments operating at other wavelengths.

Researchers used SDO data to create accurate predictions of the solar wind, which is of interest to Government agencies and private industry. The team uses ML models to predict the solar wind speed as measured at the Lagrangian Point 1 (L1) between the Sun and Earth. The best performing method is a deep neural network that uses extreme ultraviolet (EUV) imagery data from SDO as input. Without explicitly building in physical relationships into the model, it is able to outperform a number of baseline models. The model pays attention to regions on the Sun that are in agreement with heuristics used in the literature (e.g., coronal holes for the fast solar wind). Such an approach may, in the future, help researchers discover new physical process relationships in heliophysics.

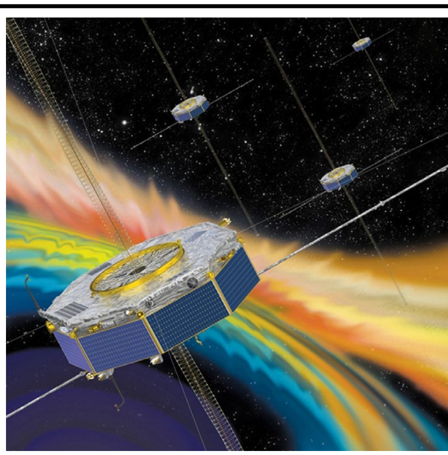
SOLAR TERRESTRIAL PROBES

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Interstellar Mapping and Acceleration Probe (IMAP)	66.2	166.3	**120.8**	144.5	59.2	39.5	23.9
Other Missions and Data Analysis	67.1	68.0	**68.0**	54.6	58.3	37.7	37.5
Total Budget	**133.3**	**234.3**	**188.8**	**199.1**	**117.5**	**77.2**	**61.4**
Change from FY 2022 Budget Request			**-45.5**				
Percent change from FY 2022 Budget Request			**-19.4%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



Shown here is an illustration of the four MMS spacecraft in orbit in Earth's magnetic field.

The Solar Terrestrial Probes (STP) Program focuses on understanding the fundamental physical processes of the space environment from the Sun to the Earth, to other planets, and beyond to the interstellar medium. STP provides insight into the basic processes of plasmas (fluids of charged particles) inherent in all astrophysical systems. STP missions focus on processes such as the variability of the Sun, responses of the planets to those variations, and the interaction of the Sun and the solar system. NASA defines specific goals for STP missions and selects investigations for each mission competitively. These missions allow the science community an opportunity to address important research focus areas and make significant progress in understanding fundamental physics.

EXPLANATION OF MAJOR CHANGES IN FY 2023

The Interstellar Mapping and Acceleration Probe (IMAP) passed its mission confirmation review in July 2021 and entered the implementation phase. The IMAP budget has been rephased to be consistent with the budget approved at confirmation. Pre-formulation work on the Dynamical Neutral Atmosphere-Ionosphere Coupling (DYNAMIC) mission is no longer supported within STP Future Missions.

ACHIEVEMENTS IN FY 2021

The Global Lyman-alpha Imagers of the Dynamic Exosphere (GLIDE) mission successfully held its System Requirements Review (SRR).

Interstellar Mapping and Acceleration Probe (IMAP) completed Phase B and passed its Preliminary Design Review (PDR). NASA confirmed IMAP to enter the final design and fabrication phase.

SOLAR TERRESTRIAL PROBES

WORK IN PROGRESS IN FY 2022

GLIDE has entered Phase C and will perform more detailed design in preparation for the Critical Design Review (CDR).

IMAP will mature its design in preparation for the CDR.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

Based on a successful CDR, GLIDE will enter the manufacturing and integration component of Phase C.

IMAP will prepare for the System Integration Review (SIR) and hold the Key Decision Point D (KDP-D).

Program Schedule

Date	Significant Event
Q2 FY 2022	GLIDE KDP-C
Q4 FY 2022	GLIDE CDR
Q4 FY 2022	IMAP CDR
Q3 FY 2023	IMAP SIR
Q3 FY 2023	IMAP KDP-D
Q2 FY 2025	IMAP LRD
Q2 FY 2025	GLIDE LRD

Program Management

Goddard Space Flight Center (GSFC) is responsible for the management of the STP Program.

SOLAR TERRESTRIAL PROBES

Acquisition Strategy

In the acquisition of STP scientific instruments, spacecraft, and science investigations, NASA will use full and open competitions to the greatest extent possible. NASA may acquire certain instruments, missions, or mission systems without competition (e.g., through international partnerships or in-house builds) if there is a clear scientific, technological, or programmatic benefit to NASA.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	SRB	Feb 2019	Program Independent Review: Assess performance of program	Successful	Nov 2023
Performance	SRB	Nov 2023	Program Independent Review: Assess performance of program	TBD	N/A

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

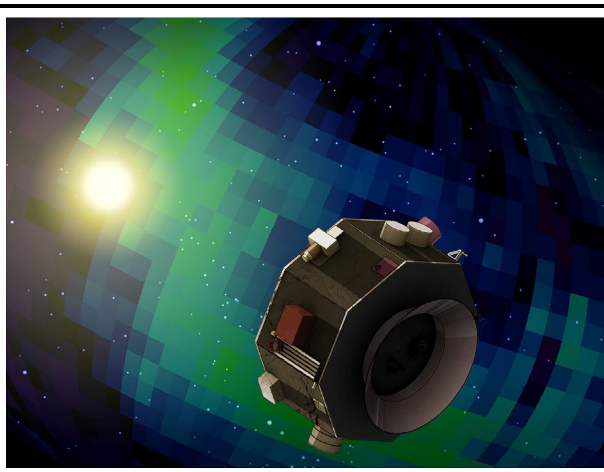
FY 2023 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027	BTC	Total
Formulation	117.6	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	117.6
Development/Implementation	28.6	66.2	166.3	**120.8**	144.5	53.0	10.0	0.0	0.0	589.5
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	6.1	29.5	23.9	15.3	74.8
2022 MPAR LCC Estimate	**146.1**	**66.2**	**166.3**	**120.8**	**144.5**	**59.2**	**39.5**	**23.9**	**15.3**	**781.8**
Total Budget	**146.1**	**66.2**	**166.3**	**120.8**	**144.5**	**59.2**	**39.5**	**23.9**	**15.3**	**781.8**
Change from FY 2022 Budget Request				**-45.5**						
Percent change from FY 2022 Budget Request				**-27.4%**						

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The 2022 MPAR LCC Estimate reflects the Fiscal Year 2022 Quarter 1 Financial Report, which is current as of December 2021. The requested budget authority is the project's current budget requirements which have seen programmatic changes approved by NASA since December 2021.



Shown here is an artist's conception of the IMAP spacecraft.

PROJECT PURPOSE

The Interstellar Mapping and Acceleration Probe (IMAP) mission will help researchers better understand the boundary of the heliosphere, a magnetic bubble surrounding and protecting Earth's solar system. This region is where the constant flow of particles from our Sun, called the solar wind, collides with material from the rest of the galaxy. This collision limits the amount of harmful cosmic radiation entering the heliosphere. IMAP will collect and analyze particles that make it through to the heliosphere.

Another objective of the mission is to learn more about the generation of cosmic rays in the heliosphere. Cosmic rays created both locally and from the galaxy and beyond affect human explorers in space and can harm technological systems, and likely play a role in the presence of life itself in the universe.

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

IMAP is the fifth mission in NASA's Solar Terrestrial Probes (STP) Program portfolio. NASA selected IMAP following an extensive and competitive peer review of proposals submitted in 2017. The mission will carry 10 science instruments provided by international and domestic research organizations and universities.

EXPLANATION OF MAJOR CHANGES IN FY 2023

IMAP passed its mission confirmation review in July 2021 and entered the implementation phase with a LCC of $781.8 million. The IMAP budget has been rephased to be consistent with budget approved at confirmation.

PROJECT PARAMETERS

IMAP will study the interaction of the solar wind with the winds from other stars by directly sampling neutral atoms returning from the interstellar boundary and will elucidate how particles are accelerated to high energies in space environments. IMAP will launch on a SpaceX Falcon 9 in 2025 and will conduct operations at the Earth-Sun Lagrange Point 1, upstream of Earth at 1 percent of the distance to the Sun. IMAP will carry ten instruments, which can be grouped into three categories: energetic neutral atom detectors (IMAP-Lo, IMAP-Hi, and IMAP-Ultra), charged particle detectors (SWAPI, SWE, CoDICE, and HIT), and other coordinated measurements (MAG, IDEX, GLOWS). Each of the ten instruments are described in the Project Management & Commitments table below. IMAP will also supply critical real-time space weather data through its IMAP Active Link for Real-Time (I-ALiRT). With I-ALiRT, IMAP will enable new ways of forecasting space weather by streaming real-time observations of conditions headed towards Earth to operators on the ground.

Up to four secondary rideshare payloads will accompany the IMAP mission, taking advantage of the excess performance capability of the launch vehicle. Heliophysics is currently planning to fly STP science (GLIDE) and technology demonstration (Solar Cruiser) missions of opportunity along with the National Oceanic and Atmospheric Administration (NOAA) Space Weather Follow-On (SWFO-L1) and the Planetary Science Lunar Trailblazer mission.

ACHIEVEMENTS IN FY 2021

NASA confirmed IMAP on July 12, 2021 following the completion of its Preliminary Design Review on May 20, 2021.

In September 2021, NASA approved an International Agreement with the United Kingdom (UK) Space Agency for the UK's contribution of the magnetometer instrument to be developed by the Imperial College of London.

WORK IN PROGRESS IN FY 2022

The project entered its critical design phase in July 2021, a phase that is marked by fabrication and testing of engineering test units of instruments, subsystems, and components. All instruments and subsystems

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

will undergo their respective Critical Design Reviews (CDR). Upon successful completion of those reviews, the project will conduct a mission-level CDR. This review will mark the advancement to the next phase of fabricating and testing flight hardware.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

In FY 2023, the instrument teams and subsystems will build, test, and deliver to the Applied Physics Laboratory (APL), the final flight hardware, following their respective System Integration Reviews (SIRs). The project will then conduct a mission-level Systems Integration Review, and NASA will conduct a KDP-D review which authorizes the project to proceed to the phase of System Assembly, Integration & Test.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2023 PB Request
KDP-C	Jul 2021	Jul 2021
CDR	Jun 2022	Nov 2022
KDP-D	May 2023	May 2023
KDP-E	Dec 2024	Dec 2024
Launch (or equivalent)	Dec 2025	Dec 2025

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2021	$589.5M	70%	2022	$589.5M	0%	LRD	12/2025	12/2025	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**589.5**	**589.5**	**0**
Aircraft/Spacecraft	67.4	67.4	0
Payloads	124.9	124.9	0
Systems I&T	26.6	26.6	0
Launch Vehicle	78.4	78.4	0
Ground Systems	33.7	33.7	0
Science/Technology	21.6	21.6	0
Other Direct Project Costs	236.9	236.9	0

Project Management & Commitments

The mission Principal Investigator is from Princeton University. The Johns Hopkins University/Applied Physics Lab (JHU/APL) is responsible for project management and engineering.

Element	Description	Provider Details	Change from Baseline
Spacecraft	Provides a controlled spinning platform at the L1 Lagrange point for an extensive payload of scientific instruments.	Provider: JHU/APL Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
IMAP-Lo Instrument	Tracks the interstellar flow to precisely determine the species-dependent flow speed, temperature, and direction of the Local Interstellar Medium (LISM) that surrounds, interacts with, and determines the outer boundaries of the global heliosphere.	Provider: University of New Hampshire Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
CoDICE Instrument	Determines the Local Interstellar Medium (LISM) composition and flow properties, to discover the origin of the enigmatic suprathermal tails and advance understanding of the acceleration of particles in the heliosphere.	Provider: Southwest Research Institute Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
IDEX Instrument	A high-resolution dust analyzer that provides the elemental composition, speed, and mass distributions of Interstellar Dust (ISD) particles.	Provider: University of Colorado Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Solar Wind and Pickup Ions (SWAPI) Instrument	Delivers the high time and energy resolution required to identify local acceleration processes, fundamental to understanding the solar wind context, sources, and acceleration of particles, PUIs, and the physical processes regulating the global heliosphere.	Provider: Princeton University Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
IMAP Ultra Instrument	Images the emission of Energetic Neutral Atoms (ENAs) produced in the heliosheath and beyond.	Provider: JHU/APL Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
HIT Instrument	Delivers full-sky coverage of ion anisotropy measurements, observing the ramps of local shocks, anchoring the high-energy SEP ion spectra, and resolving particle transport in the heliosphere.	Provider: GSFC Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
SWE Instrument	Measures in situ solar wind electrons at L1 to provide context for the ENA measurements and perform the in situ solar wind observations necessary to understand the local structures that can affect acceleration and transport.	Provider: Los Alamos National Laboratory Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
IMAP-Hi Instrument	Enables unprecedented, detailed studies of structure and evolution of source plasmas in the heliosphere-LISM interaction region.	Provider: Los Alamos National Laboratory Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
GLOWS Instrument	Measures the heliospheric resonant backscatter glow of hydrogen and helium.	Provider: Polish Academy of Science, Space Research Center Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): Poland Ministry of Science	N/A
Magnetometer Instrument	Allows new insight into waves and turbulence in the solar wind to frequencies near the electron gyrofrequency and maintains an accurate baseline for space weather applications.	Provider: Imperial College of London Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): UK Space Agency	Yes
Launch Vehicle	The Falcon 9 rocket will deliver the IMAP observatory and up to four rideshare secondary payloads to a proper orbital trajectory.	Provider: SpaceX Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: Multiple payloads are co-manifested to fly with IMAP, Then: There is a possibility of impact to the primary IMAP mission, programmatically or technically.	1) Development of Rideshare coordination processes; 2) Early identification of launch vehicle contractor; 3) Early development and strict adherence to Do-No-Harm requirements; and 4) maintain close coordination amongst all payloads (primary and secondary projects).
If: The quantity, complexity or sensitivity of IMAP instruments causes issues during development or integration and testing, Then: The project could experience the need for additional testing or redesign leading to cost and schedule impact.	1) Bring in mentors with more experience delivering science instrument hardware to provide support to the Lo and CoDICE teams; 2) External Review of High Voltage System (HV) by HV working group; 3) Identify and assign HV Systems Engineering Lead at Payload level to lead HV working Group; 4) Early Engineering Model (EM) development and test; and 5) Early EM interface tests for critical interfaces between instruments.

Acquisition Strategy

NASA competitively selected the mission through the Solar Terrestrial Program-5 AO and completed final down-selection in 2018. NASA selected the launch vehicle through full and open competition via NASA's Launch Services Program at the Kennedy Space Center (KSC).

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Mission Development, IMAP-Ultra Instrument	JHU/APL	Laurel, MD
SWAPI Instrument and Science	Princeton University	Princeton, NJ
IMAP-Hi and SWE Instruments	Los Alamos National Laboratory	Los Alamos, NM
CoDICE Instrument, Instrument Common Electronics, Payload Systems Engineering	Southwest Research Institute	San Antonio, TX
IMAP-Lo Instrument	University of New Hampshire	Manchester, NH
IDEX Instrument	Laboratory for Atmospheric and Space Physics - Colorado University	Boulder, CO

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

Element	Vendor	Location (of work performance)
Launch Vehicle	SpaceX	Hawthorne, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board	Dec 2019	System Requirements Review evaluates whether the functional and performance requirements are defined for the system. Mission Design Review evaluates whether the proposed mission/system architecture is responsive to the program mission/system functional and performance requirements.	Successful	PDR
Performance	Standing Review Board	May 2021	Preliminary Design Review demonstrates that the preliminary design meets all system of interest requirements with acceptable risk and within the cost and schedule constraints and establishes the basis for proceeding with detailed design.	Successful	CDR
Performance	Standing Review Board	Nov 2022	Critical Design Review demonstrates that the maturity of the design is appropriate to support proceeding with full-scale fabrication, assembly, integration, and test.	TBD	SIR
Performance	Standing Review Board	May 2023	Systems Integration Review ensures segments, components, and subsystems are on schedule to be integrated into the system of interest, and integration facilities, support personnel, and integration plans and procedures are on schedule to support integration.	TBD	ORR

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Standing Review Board	Nov 2024	Operations Readiness Review ensures that all system and support (flight and ground) hardware, software, personnel, procedures, supporting capabilities, and user documentation accurately reflect the deployed state of the system and are operationally ready.	TBD	N/A

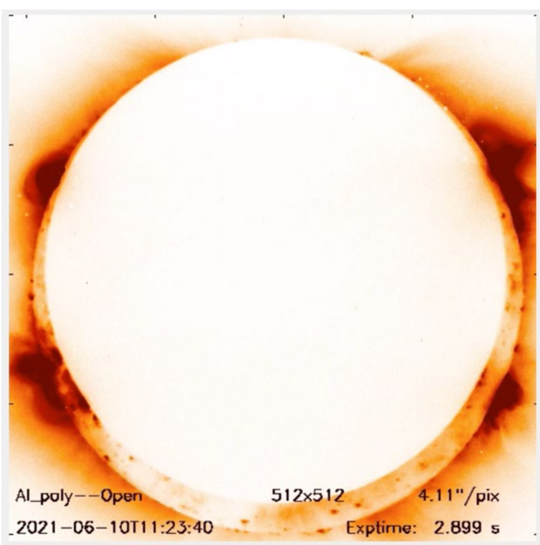
OTHER MISSIONS AND DATA ANALYSIS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Global Lyman-alpha Imager of the Dynamic	11.1	22.1	**23.7**	13.0	11.0	3.2	2.9
Solar Terrestrial Probe Future Missions	10.0	0.0	**0.0**	0.0	0.0	0.0	0.0
STP Program Management	8.9	9.9	**13.3**	9.5	15.1	4.2	4.2
Magnetospheric Multiscale (MMS)	26.0	20.8	**15.8**	16.9	16.8	15.2	15.2
Solar Terrestrial Relations Observatory (STEREO)	4.0	6.0	**6.0**	6.0	6.0	6.0	6.0
Hinode (Solar B)	5.5	7.0	**6.5**	6.5	6.5	6.5	6.5
TIMED	1.6	2.2	**2.7**	2.7	2.8	2.7	2.7
Total Budget	**67.1**	**68.0**	**68.0**	**54.6**	**58.3**	**37.7**	**37.5**
Change from FY 2022 Budget Request			**0.0**				
Percent change from FY 2022 Budget Request			**0.0%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



An annular solar eclipse (shown above) took place on June 10, 2021 and was visible with the some of the best viewing opportunities occurring on the eastern parts of the US and Canada. Hinode/XRT operates above the clouds and had no issue getting a full view of the eclipse. Since the Moon was in a position where it didn't appear as large as the Sun in the sky, there was partial blockage of the Sun even during the peak of the eclipse.

The Solar Terrestrial Probes (STP) Other Missions and Data Analysis budget includes operating STP missions, program management, and funding for future missions launching in the next decade.

Mission Planning and Other Projects

STP PROGRAM MANAGEMENT

STP Program Management provides the resources required to manage the planning, formulation, and implementation of all STP missions. The program office ensures successful achievement of STP program cost and schedule goals, while managing cross-project dependencies, risks, issues, and requirements as projects progress through formal key decision points.

OTHER MISSIONS AND DATA ANALYSIS

STP FUTURE MISSIONS

The STP Future Missions project supports strategic planning for addressing the recommendations of the Heliophysics Decadal Survey. NASA anticipates receiving recommendations from the next Heliophysics Decadal Survey in 2024.

GLOBAL LYMAN-ALPHA IMAGERS OF THE DYNAMIC EXOSPHERE (GLIDE)

In December 2020, NASA selected the GLIDE SmallSat mission as an STP Mission of Opportunity. GLIDE will study variability in Earth's exosphere by tracking far ultraviolet light emitted from hydrogen. It will also gather observations at a high rate, with a view of the entire exosphere, ensuring a global and comprehensive set of data, which is currently lacking. GLIDE will help scientists better understand the ways in which Earth's exosphere changes in response to influences of the Sun. This study will provide us with better ways to forecast and, ultimately, mitigate the ways in which space weather can interfere with radio communications in space. GLIDE will be a rideshare payload on the IMAP mission, launching no earlier than February 2025.

Recent Achievements

GLIDE successfully completed the mission Preliminary Design Review in November 2021 and entered Phase C in January 2022.

Operating Missions

MAGNETOSPHERIC MULTISCALE (MMS)

The MMS mission investigates how the magnetic fields of the Sun and Earth connect and disconnect, explosively transferring energy from one to the other, and throughout interplanetary space. MMS uses Earth's magnetosphere as a natural laboratory to study the microphysics of magnetic reconnection, a fundamental plasma-physical process that converts magnetic energy into heat and charged particle kinetic energy. In addition to seeking to solve the mystery of the small-scale physics of the reconnection process, MMS investigates how the energy conversion that occurs in magnetic reconnection accelerates particles to high energies and what role plasma turbulence plays in reconnection events. Magnetic reconnection, particle acceleration, and turbulence occur in all astrophysical plasma systems. Researchers can only study these phenomena in-situ in our solar system, and most efficiently in Earth's magnetosphere, where these processes control the dynamics of the geospace environment and play an important role in the phenomena known as space weather. MMS also helps us understand reconnection elsewhere, such as the atmosphere of the Sun and other stars, near black holes and neutron stars, and at the boundary between the solar system's heliosphere and interstellar space, where it is more difficult to study.

The MMS mission consists of four identically instrumented spacecraft that measure particles, fields, and plasmas. The MMS instrument payload measures electric and magnetic fields and the plasmas found in the regions where magnetic reconnection occurs. Fast, multi-point measurements are enabling dramatically revealing direct observations of these physical processes. A highly elliptical orbit explores how Sun-Earth magnetic fields reconnect in Earth's neighborhood. The four spacecraft fly in a tetrahedron formation that allows them to observe the three-dimensional structure of magnetic

OTHER MISSIONS AND DATA ANALYSIS

reconnection events. The separation between the observatories is adjustable over a range of 6 to 250 miles during science operations areas of interest. MMS is currently in extended operations.

MMS launched in March 2015 and entered its extended mission phase in September 2017. NASA has approved MMS to continue as an extended mission, and MMS will be invited to the 2023 Heliophysics Senior Review.

Recent Achievements

For the first time, NASA scientists have been able to reconstruct the three-dimensional time progression of magnetic reconnection events purely from satellite measurements, rather than by simulations. Using the very precise measurements on the MMS spacecraft and the full equations of the electromagnetic field, MMS researchers have been able to reconstruct the three-dimensional topology of magnetic reconnection events and show how they connect the solar wind with the magnetic field lines that lead to the Earth. Researchers demonstrated this technique for reconnection events at both the terrestrial magnetosphere's dayside boundary, as well in Earth's magnetotail.

After six years in flight and with over 125 scientific sensors operating, MMS has solved many mysteries behind the phenomenon of magnetic reconnection. These discoveries include the source of the reconnection electric field, the rate at which reconnection proceeds, the acceleration of energetic particles, and the effects of turbulent electric and magnetic fields. MMS discovered a new type of wave-particle interaction at work – low frequency waves – which likely triggers magnetic reconnection. Most surprising has been the discovery that magnetic reconnection occurs in many more regions around the Earth than previously thought possible.

This ability to reconstruct the 3D topology of reconnection purely from the satellite measurements confirms our understanding of the process of reconnection. Definitions of the theories underlying the process are now possible. There is confirmation of the energy release as sufficient to power the phenomena seen in aurora and solar storms. As a result, the techniques used to model and forecast space weather events will advance significantly.

SOLAR TERRESTRIAL RELATIONS OBSERVATORY (STEREO)

STEREO enables studies of the origin of the Sun's coronal mass ejections (CME) and their consequences for Earth, other planets, and interplanetary space. The mission launched with two spacecraft, one Ahead of Earth (STEREO-A) and the other Behind Earth (STEREO-B) in its orbit. STEREO's instrumentation targets the fundamental process of energetic particle acceleration in the low solar corona and in interplanetary space. The mission can image the structure and evolution of solar storms as they leave the Sun and move through space toward Earth. The mission also provides the foundation for understanding space weather events and developing predictive models. The models, in turn, help to identify and mitigate the risks associated with space weather events. In addition, STEREO improves space weather situational awareness not only for Earth and in low-Earth orbit, but also throughout the solar system.

On October 1, 2014, NASA lost communication with STEREO-B just as the spacecraft was about to orbit around the other side of the Sun. In late 2015, the spacecraft orbit finally carried it out from behind the Sun and NASA was able to re-establish contact with STEREO-B for a short period in 2016. NASA attempted to establish control of the spacecraft with limited success. Beginning in December 2017, the project team made monthly attempts to re-establish contact with the spacecraft, until attempts ceased in October 2018.

OTHER MISSIONS AND DATA ANALYSIS

STEREO launched in October 2006 and entered its extended mission phase in January 2009. NASA has been unable to communicate with STEREO-B since 2016. STEREO-A continues to operate nominally and is still providing significant science data. NASA has approved STEREO to continue as an extended mission, and STEREO will be invited to the 2023 Heliophysics Senior Review.

Recent Achievements

Researchers analyzed data from three well-placed spacecrafts: PSP, STEREO-A, and Solar Dynamics Observatory (SDO). They determined the CME trajectory using a tracking-and-fitting technique and verified using simultaneous images of the CME propagation from STEREO-A. The unexpected alignment with STEREO-A also provided views of coronal activity leading up to the eruption. Researchers used observations from SDO, in conjunction with potential magnetic field models of the corona, to analyze the coronal magnetic evolution for the three days leading up to the flux rope ejection from the corona. The analysis of the data suggests that restructuring of the coronal magnetic fields caused by an emerging active region led to the final ejection of the flux rope, which is an important result as the team develops better space weather predictive models.

HINODE

Hinode is a joint Japan Aerospace Exploration Agency (JAXA) and NASA mission. The mission consists of a coordinated set of optical, extreme ultraviolet, and X-ray instruments that study the basic heating mechanisms and dynamics of the active solar corona. Hinode explores the magnetic fields of the Sun to improve understanding of what powers the solar atmosphere and drives solar eruptions. By investigating the fundamental processes that connect the Sun's magnetic field and the solar corona, Hinode is discovering how the Sun generates magnetic disturbances and the high-energy particle storms that propagate from the Sun to Earth.

Hinode's solar optical telescope is the first spaceborne instrument to measure the strength and direction of the Sun's magnetic field on the Sun's surface, the photosphere. Two other Hinode instruments, the Extreme Ultraviolet (EUV) imaging spectrometer and the X-ray/EUV telescope, allow the mission to investigate the causes of eruptions in the solar atmosphere and relate those eruptions to the intense heating of the corona and the mechanisms that drive the constant outflow of solar radiation, the solar wind.

Hinode launched in September 2006 and entered its extended mission phase in November 2009. NASA has approved Hinode to continue as an extended mission, and Hinode will be invited to the 2023 Heliophysics Senior Review.

Recent Achievements

The investigation of the source of a type III radio burst storm would not be possible without a combined data of several missions, PSP, Hinode, and SDO. The observation during encounter 2 of NASA's Parker Solar Probe mission showed that there was a large amount of radio activity, and in particular a noise storm of frequent, small type III bursts from March 31st to April 6th of 2019. The source of these small and frequent bursts was unknown. After investigating, researchers found that although the active region on the disk produces no significant flares, its evolution indicates it is a source of the electron beams causing the radio storm. They most likely originate from the area at the edge of the active region that shows strong, blue-shifted plasma. The study demonstrated that as the active region grows and expands, the area of the blue-shifted region at the edge increases, which is also consistent with the increasing area where large-scale or expanding magnetic field lines from modelling are anchored.

OTHER MISSIONS AND DATA ANALYSIS

THERMOSPHERE, IONOSPHERE, MESOSPHERE ENERGETICS AND DYNAMICS (TIMED)

The TIMED mission characterizes and studies the physics, dynamics, energetics, thermal structure, and composition of the least explored and understood regions of Earth's atmosphere: the mesosphere, the lower thermosphere, and the ionosphere, collectively known as the ionosphere-thermosphere-mesosphere (ITM) system. This ITM system, located between altitudes of approximately 35 to 100 miles above the surface of Earth, helps protect Earth from harmful solar radiation. It is a gateway between Earth's environment and space, where the Sun's energy first affects Earth's environment. Solar events, as well as temperature changes in the stratosphere, can perturb this region, but scientists do not understand the overall structure of and responses to these effects. Advances in remote sensing technology employed by TIMED enable us to explore this region on a global basis from space.

TIMED's 19-years of data provides scientists an unrivaled perspective on changes in the upper atmosphere. The long lifespan allows scientists to track the upper atmosphere's response to both quick-changing conditions, like individual solar storms, throughout the Sun's 11-year activity cycle, as well as longer-term trends, such as those related to climate change. TIMED's instruments are still producing data, enabling continuing studies of the upper atmosphere.

TIMED launched in December 2001 and entered its extended mission phase in January 2004. NASA has approved TIMED to continue as an extended mission, and TIMED will be invited to the 2023 Heliophysics Senior Review.

Recent Achievements

The SABER instrument on TIMED recorded extremely cold temperatures during 2020 in the mesosphere and lower thermosphere (or MLT), which lies 50 km to 100 km (approximately 30 miles to 60 miles) above the Earth's surface. These extreme cold temperatures attribute in part to a reduction in solar activity, and in part to an increase of carbon dioxide in the MLT. Analysis of historical solar activity records indicates that the MLT in 2020 was colder than any other time since the late 1700's. This result confirms modeling studies that have predicted cooling of the upper atmosphere in response to increasing carbon dioxide levels. This cooling of the MLT is important because it causes the upper atmosphere to contract, affecting the amount of atmospheric drag on satellites and tracking of orbital debris within low-Earth orbit.

Measurements from TIMED found enhancements in the composition of the polar thermosphere between 130 to 300 km (80 to 180 miles) altitude that are related to geomagnetic activity. TIMED observed that these enhancements, or "auroral spots," rotate at speeds faster than the Earth's rotation. Such a "super-rotating" feature is new, as previous observations showed only cases where these auroral spots moved at slower speeds. The cause for the super-rotation is currently unknown, but it may involve interactions between the electric current and movement of plasma within the ionosphere, the electrically charged region of the upper atmosphere. This result shows the need for improved physical models used to predict how geomagnetic activity produced by variations in the Sun (i.e., "space weather") can affect radio and GPS signals passing through the upper atmosphere.

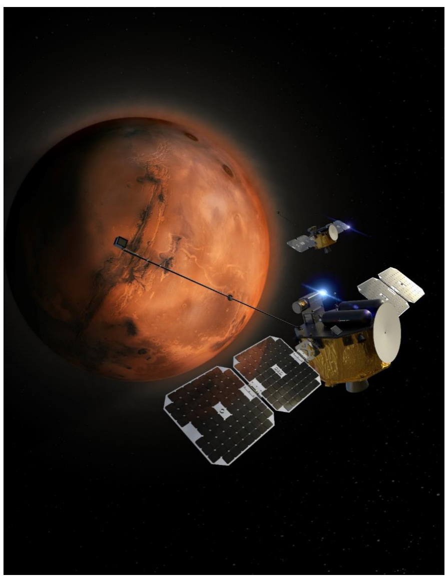
HELIOPHYSICS EXPLORER PROGRAM

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Other Missions and Data Analysis	162.7	180.2	**157.9**	190.9	222.6	270.2	307.5
Total Budget	**162.7**	**180.2**	**157.9**	**190.9**	**222.6**	**270.2**	**307.5**
Change from FY 2022 Budget Request			**-22.3**				
Percent change from FY 2022 Budget Request			**-12.4%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



Shown here is an illustration of the ESCAPADE spacecraft in orbit around Mars. ESCAPADE will study how Mars' magnetosphere – the magnetized area of space around the planet – interacts with the solar wind, and the processes driving its atmospheric escape. Credit: Rocket Lab/UCB.

The Heliophysics Explorer Program provides frequent flight opportunities for world-class scientific investigations on focused and timely science topics. These investigations complement the science of strategic missions of the LWS and STP Programs. The program is highly responsive to new knowledge, new technology, and updated scientific priorities by launching smaller missions formulated and executed in a relatively short development cycle. The program features missions that are competitively selected from the scientific research community with constrained mission life-cycle costs.

The Explorers Program provides two classes (Medium-Class Explorers [MIDEX] and Small Explorers [SMEX]) of flight opportunities to accomplish the goals of the program. MIDEX missions are the most capable Explorers scientific investigations, with a cost cap of $250 million (not including launch services). SMEX missions are focused scientific missions and are limited to a $145 million cost cap (not including launch services). Explorers Missions of Opportunity (MO) are smaller investigations, which may fly as a hosted payload, sub-orbital flight, SmallSat or CubeSat mission, or ISS-attached payloads.

EXPLANATION OF MAJOR CHANGES IN FY 2023

The Explorer Future Missions budget supports two MIDEX-19 missions, Multi-slit Solar Explorer (MUSE) and HelioSwarm, recently selected in February 2022. NASA created a new project for the Escape and Plasma Acceleration and Dynamics Explorers (ESCAPADE) investigation. The Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS) budget is adjusted to be consistent with their upcoming KDP-C mission confirmation requirements.

HELIOPHYSICS EXPLORER PROGRAM

ACHIEVEMENTS IN FY 2021

NASA selected two heliophysics missions to explore the Sun and the systems that drive space weather near Earth: Electrojet Zeeman Imaging Explorer (EZIE); and NASA's contribution to the Extreme Ultraviolet High-Throughput Spectroscopic Telescope Epsilon Mission (EUVST). The Japan Aerospace Exploration Agency (JAXA) leads the Extreme Ultraviolet High-Throughput Spectroscopic Telescope (EUVST) Epsilon Mission (Solar-C EUVST Mission), along with other international partners.

Following completion of Phase B Preliminary Design Reviews, NASA confirmed Atmospheric Waves Experiment (AWE), EscaPADE, Polarimeter to Unify the Corona and Heliosphere (PUNCH), and Sun Radio Interferometer Space Experiment (SunRISE) to enter development. The TRACERS mission completed its Preliminary Design Review at the end of FY 2021.

NASA received Concept Study Reports from each of the five proposal teams down-selected from the 2019 Heliophysics Explorer MIDEX Announcement of Opportunity (AO).

WORK IN PROGRESS IN FY 2022

NASA recently selected two of the MIDEX proposals (MUSE and HelioSwarm) to go forward into Phase B formulation, developing system requirements. NASA will release the 2022 Heliophysics Explorer Program SMEX and MO draft AO.

EZIE and EUVST are working toward their Preliminary Design Reviews and confirmation in the summer of 2022, allowing entry into Phase C for implementation and development.

AWE and SunRISE will complete their critical design and integration leading toward their environmental testing.

ESCAPADE will work with the rideshare office to finalize launch opportunities. This launch information is necessary to complete their mission design. PUNCH completed a coupled-loads analysis and was found to be compatible to fly as a rideshare with the Astrophysics mission SPHEREx. PUNCH is also working to finalize and update its mission design based on this launch opportunity.

TRACERS is preparing for its confirmation review and entry into implementation in the spring of 2022.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

The new MIDEX-19 selections MUSE and HelioSwarm will complete Preliminary Design Reviews and progress towards confirmation. NASA will make step one selections from the 2022 Heliophysics Explorer Program SMEX and MO AO.

EZIE and EUVST will work toward their Critical Design Reviews and will perform integration and testing in the summer of 2023.

AWE and SunRISE will go through their final ship reviews.

ESCAPADE and PUNCH will perform their environmental testing, final integration, and go into storage until their rideshare opportunity is ready to integrate them to the launch vehicle. TRACERS will perform environmental testing and final integration.

Program Schedule

Date	Significant Event
Q2 FY 2022	MIDEX-19 step 2 selections
Q2 FY 2022	TRACERS KDP-C
Q2 FY 2022	EZIE System Requirements Review
Q2 FY 2022	EUVST System Requirements Review
Q2 FY 2022	PUNCH Critical Design Review
Q2 FY 2022	SunRISE System Integration Review
Q4 FY 2022	SMEX/MO announcement of opportunity
Q3 FY 2022	EZIE Preliminary Design Review
Q3 FY 2022	EZIE KDP-C
Q3 FY 2022	ESCAPADE Critical Design Review
Q3 FY 2022	AWE Pre-Environmental Review
Q4 FY 2022	TRACERS Critical Design Review
Q1 FY 2023	ESCAPADE System Integration Review
Q1 FY 2023	PUNCH System Integration Review
Q1 FY 2023	MIDEX-19 System Requirements Review
Q2 FY 2023	AWE Pre-Ship Review
Q2 FY 2023	EZIE Critical Design Review
Q2 FY 2023	EUVST Preliminary Design Review
Q2 FY 2023	ESCAPADE Pre-Environmental Review
Q3 FY 2023	AWE Operational Readiness Review
Q3 FY 2023	SMEX/MO step 1 selections
Q3 FY 2023	SunRISE Pre-Ship Review
Q3 FY 2023	PUNCH Operational Readiness Review
Q4 FY 2023	TRACERS System Integration Review
Q4 FY 2024	SMEX/MO step 2 selections
Q2 FY 2025	MIDEX announcement of opportunity

HELIOPHYSICS EXPLORER PROGRAM

Program Management & Planned Cadence

The Heliophysics and Astrophysics Explorer Programs share a common program office at Goddard Space Flight Center (GSFC) and a common management structure. The Explorer Program Manager resides at GSFC, reporting functionally to the Center Director and programmatically through the Heliophysics and Astrophysics Division Directors.

The Heliophysics Explorer Program plan accommodates the Decadal Survey's recommendation of a two-to-three-year mission cadence.

Acquisition Strategy

NASA competitively selects new Explorer missions, releasing solicitations when available funding allows, with the expectation of a two-to-three-year cadence. NASA acquires launch vehicles through the Launch Services Program at KSC except when an international partner provides them under an approved agreement or when the Explorer mission is not a primary payload on the launch vehicle.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Program Independent Review	SRB	Dec 2019	Assess performance of program	Successful	Jan 2024

OTHER MISSIONS AND DATA ANALYSIS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Electrojet Zeeman Imaging Explorer	6.1	11.3	**17.0**	14.2	5.3	2.1	2.2
Escape and Plasma Accel and Dynamics Exp	29.1	19.6	**11.2**	3.6	3.0	2.4	0.0
Extreme Ultraviolet High-throughput Spec	5.7	10.3	**13.8**	10.6	6.7	4.4	5.0
Ionospheric Connection Explorer	5.4	3.7	**6.7**	7.1	7.1	7.1	7.1
Global-scale Observations of the Limb an	5.0	4.3	**4.0**	4.8	4.8	5.5	5.7
Heliophysics Explorer Future Missions	1.6	21.2	**26.2**	59.0	116.9	209.9	257.1
Heliophysics Explorer Program Management	14.2	7.4	**18.9**	18.6	15.1	10.4	9.1
Interface Region Imaging Spectogr (IRIS)	6.5	6.5	**6.5**	6.5	6.6	6.6	6.6
Interstellar Boundary Explorer (IBEX)	4.9	1.9	**1.9**	3.1	3.2	3.2	3.2
TWINS	0.1	0.0	**0.0**	0.0	0.0	0.0	0.0
Aeronomy of Ice in Mesophere (AIM)	3.7	2.0	**2.0**	3.0	3.1	3.1	3.1
Time History of Events and Macroscale In	5.6	5.2	**5.5**	5.3	5.3	5.3	5.3
ACE	2.5	2.0	**2.6**	3.1	3.1	3.1	3.1
RHESSI	0.2	0.0	**0.0**	0.0	0.0	0.0	0.0
Polarimeter to Unify the Corona and Heli	10.4	7.5	**5.0**	19.6	27.6	1.8	0.0
Tandem Reconnection and Cusp Electrodyna	28.7	63.7	**12.9**	22.1	8.8	1.6	0.0
Atmospheric Wave Experiment	10.5	0.3	**4.1**	5.0	5.0	3.7	0.1
Sun Radio Interferometer Space Experimen	22.6	13.4	**19.6**	5.3	1.0	0.0	0.0
Total Budget	**162.7**	**180.2**	**157.9**	**190.9**	**222.6**	**270.2**	**307.5**
Change from FY 2022 Budget Request			**-22.3**				
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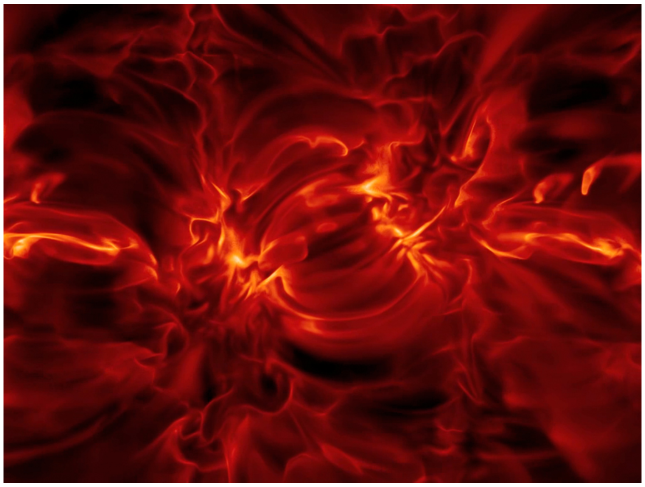
OTHER MISSIONS AND DATA ANALYSIS



Scientists are using one of the world's fastest supercomputers, named Pleiades and located at NASA Ames Research Center, to produce simulations based on IRIS images. These models may help explain how the outer solar atmosphere is shaped and heated, and how magnetic fields generated in the Sun's interior affect its lower atmosphere. Credit: Mats Carlsson, University of Oslo.

The Heliophysics Explorer Other Missions and Data Analysis budget includes operating Explorer missions, program management, missions in formulation and development with life cycle costs less than $250 million, and funding for future mission selections.

Mission Planning and Other Projects

POLARIMETER TO UNIFY THE CORONA AND THE HELIOSPHERE (PUNCH)

The PUNCH mission will focus directly on the Sun's corona and how the corona generates the solar wind. Comprised of four suitcase-size satellites, PUNCH will image and track the solar wind as it leaves the Sun. The spacecraft will also track coronal mass ejections (i.e., large eruptions of solar material that can drive large space weather events near Earth) to better understand their evolution and develop new techniques for predicting such eruptions. These observations will enhance research by other NASA missions, such as Parker Solar Probe and the ESA/NASA Solar Orbiter. PUNCH will be able to image, in real time, the structures in the solar atmosphere that these missions encounter by blocking out the bright light of the Sun and examining the much fainter atmosphere. Together, these missions will investigate how the star we live with drives radiation in space.

NASA selected PUNCH under the 2016 Small Explorers (SMEX) Announcement of Opportunity (AO). PUNCH completed preliminary design and technology (Phase B), and successfully entered the development phase in July 2021. PUNCH is in implementation (Phase C) with the critical design review scheduled in March 2022 and an expected launch date in April 2025. PUNCH will fly as a rideshare with the Astrophysics mission SPHEREx.

TANDEM RECONNECTION AND CUSP ELECTRODYNAMICS RECONNAISSANCE SATELLITES (TRACERS)

The TRACERS mission will observe particles and fields at the Earth's northern magnetic cusp region (i.e., the region encircling Earth's pole) where our planet's magnetic field lines curve down toward Earth. Here, the field lines guide particles from the boundary between Earth's magnetic field and interplanetary space down into the atmosphere. In the northern magnetic cusp area, with its easy access to our boundary with interplanetary space, TRACERS will study how magnetic fields around Earth interact with those from the Sun. In a process known as magnetic reconnection, the field lines explosively reconfigure, sending particles out at speeds that can approach the speed of light. Earth's magnetic field will guide some of these particles into the region where TRACERS can observe them.

OTHER MISSIONS AND DATA ANALYSIS

Magnetic reconnection drives energetic events all over the universe, including coronal mass ejections and solar flares on the Sun. It also allows particles from the solar wind to push into near-Earth space, affecting its space weather. TRACERS will be the first space mission to explore this process in the cusp with two spacecraft, providing observations of how processes change over both space and time. The cusp vantage point also permits simultaneous observations of reconnection throughout near-Earth space. Thus, it can provide important context for NASA's Magnetospheric Multiscale mission, which gathers detailed, high-speed observations as it flies through single reconnection events at a time. TRACERS' unique measurements will help with NASA's mission to safeguard technology and astronauts in space.

TRACERS successfully passed its System Requirements Review in May 2021 and Preliminary Design Review in October 2021. NASA is exploring rideshare opportunities for TRACERS, with KDP-C planned for the spring of 2022.

ATMOSPHERIC WAVE EXPERIMENT (AWE)

AWE will observe how atmospheric gravity waves in the lower atmosphere, caused by variations in the densities of different packets of air, affect the upper atmosphere. These observations will provide a broader understanding of space weather interactions, specifically the relation between terrestrial weather below and the solar wind. This interaction occurs in a dynamic region of the upper atmosphere and is important to understand due to the interference it can create in radio and GPS communications. NASA will attach AWE to the exterior of the ISS, where it will focus on colorful bands of light in Earth's atmosphere, called airglow, to determine what combination of forces drive space weather in the upper atmosphere.

AWE completed ISS phase II safety review in July 2021. The expected launch date is December 2023 on Dream Chaser Cargo 2.

SUN RADIO INTERFEROMETER SPACE EXPERIMENT (SUNRISE)

SunRISE will use six solar-powered CubeSats, each about the size of a toaster oven, to simultaneously observe radio images of low-frequency emission from solar activity and share them via NASA’s Deep Space Network. The constellation of CubeSats will fly within six miles of each other above Earth's atmosphere, which otherwise blocks the radio signals SunRISE will observe. Together, the six CubeSats will create 3D maps to pinpoint where giant particle bursts originate on the Sun and how they evolve as they expand outward into space. This will help determine what initiates and accelerates these giant jets of radiation. The six individual spacecraft will also work together to map the pattern of magnetic field lines reaching from the Sun out into interplanetary space. This information will help improve understanding of how our solar system works and, ultimately, can help protect astronauts traveling to the Moon and Mars by providing better information on how the Sun’s radiation affects the space environment through which they must travel.

SunRISE completed preliminary design and technology (Phase B), and successfully passed Key Decision Point C review in September 2021. SunRISE is in implementation (Phase C) with the Systems Integration Review (SIR) scheduled in March 2022 and an expected launch date no earlier than September 2025.

OTHER MISSIONS AND DATA ANALYSIS

EXTREME ULTRAVIOLET HIGH-THROUGHPUT SPECTROSCOPIC TELESCOPE EPSILON MISSION (EUVST)

In December 2020, NASA selected the EUVST mission (proposed as an Explorer Mission of Opportunity), as a contribution to the JAXA partner-led Epsilon Mission (Solar-C EUVST Mission), along with other international partners. Targeted for launch in 2027, EUVST is a solar telescope that will study how the solar atmosphere releases solar wind and drives eruptions of solar material. These phenomena propagate out from the Sun and influence the space radiation environment throughout the solar system. NASA's hardware contributions to the mission include an intensified UV detector and support electronics, spectrograph components, a guide telescope, software, and a slit-jaw imaging system to provide context for the spectrographic measurement.

ELECTROJET ZEEMAN IMAGING EXPLORER (EZIE)

In December 2020, NASA selected the Electrojet Zeeman Imaging Explorer (EZIE) mission (proposed as an Explorer Mission of Opportunity) to study electric currents in Earth's atmosphere linking aurora to the Earth's magnetosphere – one piece of Earth's complicated space weather system, which responds to solar activity and other factors. The Auroral Electrojet (AE) index is a common measure of geomagnetic activity levels, even though scientists do not yet understand all the details of the structure of these currents. EZIE is a trio of SmallSats that will launch together, no earlier than June 2024.

ESCAPE, PLASMA, ACCELERATION AND DYNAMIC EXPLORERS (ESCAPADE)

EscaPADE will study the active processes in Mars' magnetosphere and how the solar wind controls them. Using two identical SmallSats, EscaPADE will be the first mission to characterize the flow of the solar wind and of Mars-produced plasma through the Mars space environment with the ability to distinguish variations in space (e.g., a spacecraft passes through a structure) and in time (e.g., a structure changes size). The mission will focus on the plasma boundaries that define the regions of Mars' magnetosphere, Mars' atmospheric escape, and global changes in the magnetospheric structure under different solar wind conditions. With its thin atmosphere and weak crustal magnetic field in the southern hemisphere, Mars allows the study of fundamental physical processes and their differences across different planetary environments (such as compared to Earth and Venus). Further, characterizing the global system and its variability is a necessary component of understanding the space weather environment ahead of any crewed mission to Mars.

The project team is working with the Science Mission Directorate's Rideshare Office to plan for a ride to space. The EscaPADE team completed and passed their preliminary design review and NASA confirmed the project proceed to development (Phase C). EscaPADE has a planetary launch window in December of 2024.

EXPLORER FUTURE MISSIONS

Explorer Future Missions funding will support future Explorer missions that have yet to be selected. A typical Explorer mission cadence is an average of two to three years between AOs with alternating SMEX and MIDEX selections. A SMEX AO is planned in 2022 and MIDEX AO in 2025.

OTHER MISSIONS AND DATA ANALYSIS

EXPLORER PROGRAM MANAGEMENT

Explorer Program Management encompasses the program office resources required to manage Explorer projects. The program office is responsible for providing support and guidance to projects in resolving technical and programmatic issues and risks; for monitoring and reporting technical and programmatic progress of the projects; and for achieving Explorer cost, schedule, and technical goals and requirements. Support for the Science Office for Mission Assessments (SOMA) at Langley Research Center is also included in Explorer Program Management. SOMA is responsible for the technical and scientific evaluation of Explorer mission proposals.

Operating Missions

IONOSPHERIC CONNECTION EXPLORER (ICON)

ICON launched in 2019 and studies the ionosphere by simultaneously measuring altitude profiles of the thermosphere and ionosphere's neutral winds, composition, density, temperature, and ion density. It also makes in-situ plasma measurements. Understanding what drives variability in the ionosphere requires a careful look at a complicated system driven by both terrestrial and space weather. ICON studies the frontier of space, which is the dynamic zone high in our atmosphere where Earth's weather meets space weather. This is a hard-to-reach area that, despite being close to home, remains mysterious. ICON provides in-situ measurements of this complicated region of near-Earth space, which can be difficult to fly through given the variable drag on spacecraft. Radio communications and GPS signals travel through the ionosphere, and variations in this region can result in distortions, or even complete disruption, of these signals. As spacecraft travel through this region regularly, improved knowledge will increase NASA's situational awareness to protect satellites and astronauts.

ICON will help determine the physics of our space environment and pave the way for mitigating its effects on technology, communications systems, and society. ICON completed its prime mission in December 2021 and is in interim extended operations until the 2023 Heliophysics Senior Review.

Recent Achievements

Data from two instruments on board ICON together show the first direct measurements of a wind-driven dynamo in space by demonstrating a clear relationship between ionospheric plasma velocities at the magnetic equator near 600 km (360 miles) altitude and winds within the thermospheric dynamo region between 100 to 150 km (60 to 90 miles) altitude. Winds in this dynamo region are driven by atmospheric waves and tides that are generated near the Earth's surface and travel up into the thermosphere. These new ICON measurements demonstrate that models used to predict the effects of space weather on the thermosphere and ionosphere need to have accurate knowledge of lower atmospheric conditions from the surface to 150 km altitude.

Observations of thermospheric winds from ICON, together with measurements of ionospheric electrical currents from the European Space Agency's Swarm satellite mission, show how these winds form the equatorial electrojet, a region of enhanced electrical current flowing along the magnetic equator. ICON data show that east-west wind speeds in the thermosphere are significantly different between periods of eastward and westward equatorial currents, a result that confirms theoretical predictions of how thermospheric winds drive ionospheric currents that in turn produce rapid changes in the total electron content (TEC) of the ionosphere. These new results from ICON will help improve predictions of equatorial and low-latitude TEC, a critical factor affecting how signals used by space-based communication and navigation systems travel through the ionosphere.

GLOBAL-SCALE OBSERVATIONS OF THE LIMB AND DISK (GOLD)

GOLD, launched in 2018, performs unprecedented imaging of Earth's thermosphere and ionosphere. GOLD is the first mission to study the weather of the thermosphere-ionosphere rather than its climate and is the first NASA mission to fly as a hosted payload on a commercial communications satellite, pioneering cost-effective access to geostationary orbit. Capturing never-before-seen images of Earth's upper atmosphere, GOLD explores our space environment, which is home to astronauts.

For the first time, GOLD will answer fundamental scientific questions about how the thermosphere/ionosphere system responds to geomagnetic storms, solar radiation, and upward propagating waves and tides. Gathering observations from geostationary orbit above the Western Hemisphere, GOLD measures the temperature and composition of neutral gases in Earth's thermosphere. This part of the atmosphere co-mingles with the ionosphere's charged particles. Both the Sun from above and terrestrial weather from below can change the types, numbers, and characteristics of the particles found here. GOLD helps track those changes.

Activity in this region is responsible for a variety of key space weather events. GOLD scientists are particularly interested in the cause of dense, unpredictable bubbles of charged gas that appear over the equator and tropics, sometimes causing communication problems. As scientists discover the very nature of the Sun-Earth interaction in this region, the mission could ultimately lead to ways to improve forecasts of such space weather and mitigate its effects. GOLD completed its prime mission in October 2020 and is currently in extended operations and will attend the 2023 Heliophysics Senior Review.

Recent Achievements

GOLD observations show evidence of equatorial plasma bubbles (EPBs) over the Atlantic Ocean. EPBs are short-lived features in the nighttime ionosphere that can interfere with radio frequency transmissions from space to Earth, degrading the performance of space-based communication and navigation system. GOLD data, in combination with other satellite data and theoretical model simulations, now reveal that atmospheric waves produced by weather systems near the surface play a key role in EPB development.

New results from GOLD show that the solar wind plays a larger role in heating the thermosphere, the atmospheric region between 50 to 375 miles (85 to 600 kilometers), than previously expected. The thermosphere is home to the highest temperatures in Earth's atmosphere, up to 2700 F (1500 C). Absorption of high-energy X-rays and extreme ultraviolet (EUV) radiation from the Sun heats the thermosphere while protecting the surface from these types of harmful radiation. New findings from GOLD indicate that X-ray and EUV absorption do not produce all this heating. The solar wind - the particles and magnetic fields continuously escaping the Sun - also plays an important role. Some amount of thermospheric heating by the solar wind is expected near Earth's poles, where a weak point in Earth's magnetic field allows the solar wind to enter the thermosphere. GOLD's data shows temperature increases across the whole globe in response to changes in the solar wind - even near the equator, far from the polar regions. These new results indicate that variations in the solar wind alter global circulation patterns to produce heating throughout the entire thermosphere.

OTHER MISSIONS AND DATA ANALYSIS

INTERFACE REGION IMAGING SPECTROGRAPH (IRIS)

IRIS, launched in 2013, joined a network of solar spacecraft and ground-based observatories to provide unprecedented insight into a little understood region of the Sun called the interface region. IRIS makes use of high-resolution observations and state-of-the-art computer models to unravel how matter, light, and energy move through the dense region of solar material at the bottom of the Sun's atmosphere. Understanding the interface between the Sun's surface and its atmosphere, the corona, is crucial to understanding what drives heat and energy into the corona, as well as what powers solar flares and coronal mass ejections.

IRIS provides key insights into all these processes, and thereby advances our understanding of the solar drivers of space weather from the corona to the far heliosphere by combining high-resolution imaging and spectroscopy for the entire chromosphere and adjacent regions. IRIS is currently in extended operations and will attend the 2023 Heliophysics Senior Review.

Recent Achievements

The dynamic nature of the solar interior and the magnetic fields that pierce its surface generate and power the region above the visible surface of the Sun, known as the chromosphere. The chromosphere is a region that is heated to 20,000 degrees Celsius and generates much of the ultraviolet emission that impacts the Earth's upper atmosphere. A recent 2021 study combined high-resolution IRIS data with high quality observations from the ground to reveal the emergence and rise of internetwork magnetic fields into the outer solar atmosphere. These studies are important to understand the energization of the outer solar atmosphere where most of the ultraviolet emissions from the Sun originate. These solar ultraviolet emissions impact the Earth's upper atmosphere in many ways, including the energization of the Earth's ionosphere – critical for terrestrial radio propagation and GPS navigation – and the activation of Earth's upper atmospheric chemistry which affects compounds such as ozone and nitrogen oxides.

INTERSTELLAR BOUNDARY EXPLORER (IBEX)

IBEX launched in 2008 and is the first mission designed to image the edge of the solar system. As the solar wind from the Sun flows out beyond Neptune, it collides with the material between the stars, forming several boundaries. These interactions create energetic neutral atoms, particles with no charge that move very quickly. This region emits no light that conventional telescopes can see, therefore IBEX measures particles that happen to be traveling inward from the boundary instead. IBEX contains two detectors designed to collect and measure energetic neutral atoms, providing data about the mass, direction of origin, and energy of these particles. From these data, researchers create maps of the boundary every six months.

The mission's focused science objective is to discover the nature of the interactions between the solar wind and the interstellar medium at the edge of the solar system. This region is important because it shields a large percentage of harmful galactic cosmic rays from Earth and the inner solar system. IBEX is currently in extended operations and will attend the 2023 Heliophysics Senior Review.

Recent Achievements

During FY 2021, IBEX continued to map fast, electrically neutral particles, or Energetic Neutral Atoms (ENAs) that traveled the distance from the edge of the heliosphere to Earth's vicinity. A substantial solar wind pulse that NASA reported on in 2014 continues to push its way through the heliosphere boundary. The response of the heliosphere to large-scale changes in solar output has revealed three-dimensional

(3D) distances to the heliosphere's boundaries and the source regions of different ENA populations. By estimating the time it takes for solar wind and ENAs to travel between the outer heliosphere and Earth, researchers can derive the distance to the heliosphere boundaries for the first time in 3D. A study reveals asymmetries in the heliosphere's shape, finding that the heliotail extends at least ~350 Astronomical Units (AU) from the Sun, a distance that is limited by the analysis technique. This maximum distance of the heliotail is three times as far away as the Voyager's crossing into the interstellar medium in the nose direction.

AERONOMY OF ICE IN THE MESOSPHERE (AIM)

AIM, launched in 2007, is a mission to determine why polar mesospheric clouds form and why they vary. Polar mesospheric clouds (PMCs), Earth's highest-altitude clouds, form each summer in the coldest part of the atmosphere about 50 miles above the polar regions. When ice crystals form over tiny microparticles produced when meteors burn up in Earth's atmosphere, they create polar mesospheric clouds. These clouds have been steadily increasing over the past decade. PMCs are of particular interest, as the number of clouds in the middle atmosphere, or mesosphere, over Earth's poles has been increasing over recent years, possibly related to climate change. The spacecraft completed its prime mission in FY 2009. AIM is currently in extended operations and will attend the 2023 Heliophysics Senior Review.

Recent Achievements

Long-term records of temperature from AIM, combined with data from NASA's TIMED mission, confirm that the mesosphere region between 50 to 85 km (approximately 30 to 50 miles) altitude is cooling at a rate between 1 to 2 degrees C per decade due to greenhouse gas increases. This cooling is causing the mesopause region to contract at a rate of 150 to 200 meters per decade. Models had predicted the cooling and contracting of the Earth's upper atmosphere in response to increasing greenhouse gases, but AIM data provides important confirmation of this result. This contraction of the upper atmosphere affects the amount of atmospheric drag on satellites and the tracking of orbital debris within low-Earth orbit.

Analysis of AIM data over a 14-year period provides new information on meteoric smoke particles entering the upper atmosphere. Instruments on AIM detect nanometer-sized smoke particles from tiny meteoroids burning up as they enter the upper atmosphere at high latitudes. Metals compose these smoke particles and can interfere with radio signals passing through the lowermost D-region of the ionosphere. These particles can also seed formation of PMCs near 85 km (50 miles) altitude. Solar Occultation For Ice Experiment (SOFIE) observations show a global mean meteoric influx of approximately 7 tons per day, in good agreement with models and other independent observations. SOFIE observations also show differences in the amount of meteoric smoke between the Northern Hemisphere and Southern Hemisphere that are larger than model predictions, suggesting that some important physical processes may be missing from these models.

TIME HISTORY OF EVENTS AND MACROSCALE INTERACTIONS DURING SUBSTORMS (THEMIS)

THEMIS is a MIDEX mission that launched in February 2007. Starting as a five-spacecraft mission, the three inner probes of THEMIS now focus on collecting data related to the onset and evolution of magnetospheric substorms, while the two outer probes (now referred to as ARTEMIS) have been repositioned into lunar orbits. Magnetospheric substorms are the explosive release of stored energy within the near-Earth space environment that can lead to space weather effects. The two ARTEMIS probes orbit the Moon’s surface at approximately 100 miles in altitude and provide new information about the Moon’s internal structure and its atmosphere. ARTEMIS provides two-point observations essential to characterizing the Moon’s plasma environment and hazardous lunar radiation. THEMIS and ARTEMIS, among others in the Heliophysics portfolio, are examples of missions offering important dynamics knowledge useful for future human spaceflight. THEMIS is currently in extended operations and will attend the 2023 Heliophysics Senior Review.

Recent Achievements

THEMIS quantified near-hazardous geoelectric fields produced over North America during times of moderate geomagnetic activity in coordination with ground-based observations, including radar, magnetometers, and electric field instruments. This combined data set included two geomagnetic storms that showed strong, correlated low-frequency electromagnetic waves in the magnetosphere and on the ground, accompanied by strong perturbations in ionospheric flow velocities. These geoelectric fields were about 1 volt/kilometer, or a third of the amplitude where they are known to induce damaging currents in power grids and other infrastructure. While periods of strong geomagnetic activity are the best time to recognize these fields, this result is the first coordinated study that shows their occurrence during times of weaker activity too. Understanding how and when this phenomenon is generated across a range of conditions is a necessary part of enabling their full treatment in space weather forecasting and prediction.

THEMIS/ARTEMIS made key observations of photoelectrons from the Moon's surface, including the first observations of their production from atomic oxygen and the production of higher-energy photoelectrons by solar x-rays (up to ~500 electron-volts, compared to previous observations of ~20 electron-volts). Neutral atoms at the surface emit these photoelectrons when struck by solar photons. These electrons modify the dynamics of the near-Moon plasma and of charged dust, which directly impact orbiting and landed assets. Fully understanding and predicting the potential hazards to human and robotic lunar exploration requires incorporating the effects of these photoelectrons. However, limited observations hinder refining and constraining models describing their occurrence and strength. The THEMIS/ARTEMIS study has provided a lower limit of the photoelectron yield from solar ultraviolet light and x-rays and provides a necessary input for laboratory work and modeling that is part of the path for improving the safety and reliability for lunar exploration.

ADVANCED COMPOSITION EXPLORER (ACE)

ACE launched in 1997 and observes particles of solar, interplanetary, interstellar, and galactic origins as they pass by its location near the L1 Lagrange point, located about one million miles from Earth toward the Sun. Changing conditions over the solar cycle are presenting new opportunities, including providing new insights relevant to space weather events.

In late 2019, the National Oceanic and Atmospheric Administration (NOAA) requested that ACE be designated a permanent operational asset, supported by NASA. It will continue to provide essential and continuous space weather observations from its location at the Earth’s L1 point. The spacecraft has enough propellant on board to maintain an orbit at L1 until approximately 2024. ACE is currently in extended operations.

Recent Achievements

Solar flare eruptions and Coronal Mass Ejections along with the associated shock waves can produce radiation that fills most or all of the inner heliosphere. This radiation can impact space assets and commercial airline travel, and the associated shocks can interfere with radio communication, and power

OTHER MISSIONS AND DATA ANALYSIS

networks on the ground. After the deep solar sunspot minimum in 2018-2019, sunspot activity began to increase in 2020 when the Heliospheric constellation of ACE, STEREO, and the newly launched Parker Solar Probe (PSP) and Solar Orbiter spacecraft were positioned to give a global view of such events. The first sizable particle event of Solar Cycle 25 occurred on Nov 29, 2020, erupting on the back side of the Sun as seen from Earth, but well observed by the global spacecraft constellation. Observing multiple events over the upcoming solar activity cycle will permit scientists to test and refine models of these large shock events, greatly improving our ability to forecast their likely affects throughout the inner solar system.

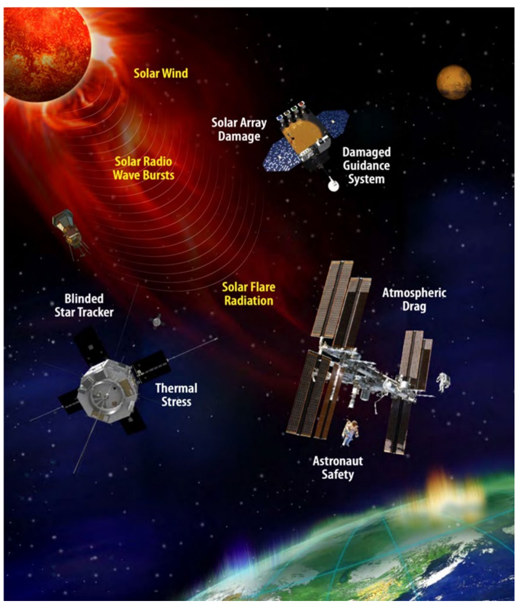
SPACE WEATHER

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**44.3**	**26.5**	**22.3**	**31.9**	**34.5**	**24.2**	**22.7**
Change from FY 2022 Budget Request			**-4.2**				
Percent change from FY 2022 Budget Request			**-15.8%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



Solar activity and the resulting natural processes known as "space weather" can damage satellites and poses a significant risk to astronaut health and safety. Space weather can also interfere with satellite tracking and may cause unexpected changes to the orbital debris population, increasing the likelihood of catastrophic collisions in the increasingly congested low-Earth orbit (LEO) operating environment.

Space weather phenomena pose a significant threat to ground-based and space-based critical infrastructure, modern technological systems, and humans working in space. The NASA Space Weather Program plays a vital role in the national space weather enterprise by providing unique and impactful observations and data streams for theory, modeling, and data-driven analysis. This program also supports enabling research and facilitates the transition of this research into solutions for the Nation's operational space weather needs. NASA's contributions to observing and understanding space weather will enable the Nation to better protect technology and astronauts from space weather.

The NASA Space Weather Program involves a diverse mixture of activities including competed research, directed and competed flight components, and interagency and international cooperation. This approach allows the program to address gaps in national space weather capabilities wherever they are found and serves to enable the efficient maturation of technologies and subsequent transfer of critical new capabilities to partner agencies such as the National Oceanic and Atmospheric Administration (NOAA) and the Department of Defense (DoD).

EXPLANATION OF MAJOR CHANGES IN FY 2023

The Heliophysics Space Weather Program is a new program in the FY 2023 budget. The program includes the Space Weather Science and Applications (SWxSA) project, the Heliophysics Environmental and Radiation Measurement Experiment Suite (HERMES), and the Space Weather Future Missions projects. Both the SWxSA and the HERMES projects were previously in the Living With a Star Program.

SPACE WEATHER

ACHIEVEMENTS IN FY 2021

HERMES successfully completed Single Design Review and will now proceed through fabrication and delivery. Additionally, the Gateway Program moved HERMES to HALO (Habitation And Logistics Outpost) module to improve science return potential of the payload.

NASA commissioned and received the Space Weather Science and Observation Gap Analysis and the National Academy report of the phase-one Space Weather Infrastructure workshop entitled "Planning the Future Space Weather Operations and Research Infrastructure." These two reports will allow the program to proceed with future activities that have the largest impact. Additionally, NASA initiated a monthly Agency-wide space weather monthly status review for the various space weather-relevant activities across the Agency to consolidate understanding and leverage activities within the Agency.

The existing Space Weather Operations to Research (SWO2R) element has been restructured and expanded into the Space Weather Research to Operations to Research (SWR2O2R) element. In addition to providing clearer recognition that operational solutions can flow up from fundamental research, this change also introduced a new "transition step" that provides an extra year of support to prepare research products and capabilities for transition to partner agencies within the Space Weather community, such as NOAA and DoD. The first ROSES selection for SWR2O2R occurred in the fall of 2021, with research being solicited to address capability needs in the forecasting of Solar Flare Activity and the Cislunar Space Environment.

WORK IN PROGRESS IN FY 2022

NASA approved HERMES to proceed into development in January 2022. The project will complete instrument deliveries to Goddard Space Flight Center (GSFC) by July 2022 to begin payload integration and testing.

NASA will expand its investments in the maturation of research to support space weather forecasting through two new openly competed research elements, "Space Weather Centers of Excellence" (Centers) and "Space Weather Applied Research Challenges" (SWARC). The SWARC element will support targeted research that can remove scientific and technological roadblocks to improve space weather capabilities, but which are not currently within scope of the SWR2O2R element. The Centers are a direct response to language from PROSWIFT Act that called on NASA to "support competitively awarded grants for multidisciplinary science centers that advance solar and space physics research, including research-to-operations and operations-to-research processes."

The NASA Space Weather Program expects to commission the National Academies to conduct a follow-on Phase-two workshop focused on research required to undergird a national space weather operational network. This will promote and provide insight as to how to create an international space weather strategic and collaborative forum among national and international agencies responsible for implementing space weather-relevant research and operations.

The program will begin supporting the development of small satellite missions, CubeSats, to mature and demonstrate new technologies and observing strategies to address areas of concern identified in the Gap Analysis and other strategic needs. NASA plans an initial cohort of four CubeSats with two focusing on improving observations of the solar drivers of space weather, one focused on the atmospheric drivers of space weather, and one focused on measuring the combined impacts of these drivers on the Earth's ionosphere where communication and navigation are vulnerable to disruption.

SPACE WEATHER

The program will continue to bring new projects under its umbrella including onboarding the Mars Science Laboratory (MSL) Radiation Assessment Detector (RAD) instrument into the Heliophysics fleet of missions as an instrument for space weather associated with deep space exploration. The program will assume responsibility of funding the MSL RAD investigation and data distribution through the Space Physics Data Facility (SPDF) in addition to the current Planetary Data System (PDS). The value of this action is that data from the MSL RAD will be an outpost and a ground-truth data source for the development of space weather models in support of deep space human exploration.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

NASA will deliver HERMES for storage in December 2022 after completion of integration and testing. NASA will begin final mounting, testing, and preparations for shipping to launch the site late in the fiscal year.

NASA will establish an instrument technology and rideshare competed program element that focuses on developing space weather instruments and small payloads flown on missions of opportunities to form the basis for future space weather research missions.

The program will continue to solicit competed research proposals for its SWR2O2R and SWARC solicitations.

Program Elements

SPACE WEATHER SCIENCE AND APPLICATIONS (SWxSA)

The SWxSA project works to support the effective transition of heliophysics science results, tools, technology, and techniques to applications that enhance the user communities' ability to address impacts caused by the dynamic space environment. To accomplish this, the SWxSA program supports competitively funded research as well as directed and competed technology and payload development and engages with user agencies to understand their space weather needs and user communities to understand how they are impacted. This activity is NASA's primary touchpoint for interagency space weather efforts and is consistent with the recommendations of the National Academy 2013 Decadal Survey for Solar and Space Physics, the Office of Science and Technology Policy 2019 National Space Weather Strategy and Action Plan, and the PROSWIFT Act of 2020.

Specific activities within the SWxSA project include Space Weather Research to Operations to Research, Space Weather Centers of Excellence, Space Weather Applied Research Challenges, and the HERMES Interdisciplinary Scientist elements. These activities all serve to empower the research community to tackle critical and emerging challenges in space weather.

HELIOPHYSICS ENVIRONMENTAL AND RADIATION MEASUREMENT EXPERIMENT SUITE (HERMES)

HERMES will be a space weather payload on the Gateway (an outpost in lunar orbit) as part of NASA's Artemis Campaign. The payload will be comprised of a suite of high-maturity instruments that will enable meaningful science in the lunar environment, support crew safety at the Moon, and be a pathfinder for future missions to Mars.

SPACE WEATHER

HERMES will launch with the first two elements of the Gateway. HERMES will enable the investigation of fundamental science questions like the acceleration mechanisms of solar energetic particles, variability of solar wind structures and Galactic Cosmic Rays, and magnetotail dynamics. Data collected by HERMES will also provide critical safety information for astronaut operations in the lunar environment. HERMES will support operational forecasting and nowcasting, or prediction of current events, of solar energetic particles that pose a risk to astronauts during extravehicular activities on the Gateway or the lunar surface.

In coordination with the two-spacecraft mission THEMIS and ARTEMIS already in lunar orbit, HERMES will comprise a heliophysics lunar constellation that enables science investigations and space weather observations not possible before now. A second payload installed on the Gateway (European Radiation Sensors Array, provided by the European Space Agency) will further amplify the work of HERMES by providing additional data characterizing high-energy particles that are dangerous to crew safety.

SPACE WEATHER FUTURE MISSIONS

The Space Weather Future Missions project will support future space weather investigations or future NASA participation in international space weather mission which could provide valuable science data to advance understanding of the dynamics of the solar surface and improve space weather predictions.

Program Schedule

Date	Significant Event
Q1 FY 2022	ROSES-2021 SWR2O2R selections
Q1 FY 2022	HERMES Single Design Review (SDR)
Q2 FY 2022	HERMES KDP-C
Q2 FY 2022	ROSES-2022 SWR2O2R and Centers of Excellence solicitations
Q2 FY 2022	ROSES-2022 SWR2O2R and Centers of Excellence selections no earlier than six months after receipt of proposals
Q3 FY 2022	HERMES delivery for integration
Q1 FY 2023	HERMES pre-ship review
Q2 FY 2023	ROSES-2023 SWR2O2R solicitation
Q2 FY 2023	ROSES-2023 SWR2O2R selections no earlier than six months after receipt of proposals

Program Management & Commitments

Program Element	Provider
Space Weather Science and Applications	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, HQ, JPL, LaRC, MSFC Cost Share Partner(s): None
HERMES	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): None

Acquisition Strategy

NASA primarily procures tasks through full and open competition, such as the ROSES announcements. The solicitation of technology investments is competitive and selected from NASA Centers, industry, and academia, as well as other Government agencies, Federally Funded Research and Development Centers, and nonprofit organizations. NASA may directly fund critical technologies identified through a gap analysis.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Relevance	Johns Hopkins Applied Physics Laboratory	2021	Independent assessment of space weather measurement needs	Results are being used to inform Space Weather Program investment priorities	TBD
Relevance	National Academies of Science	2021	Planning future space weather operations and research infrastructure	Results are being used to inform Space Weather Program investment priorities	FY 2022

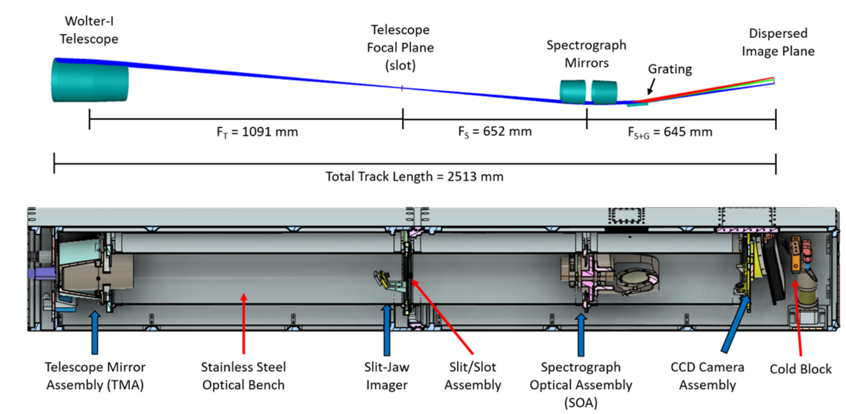
HELIOPHYSICS TECHNOLOGY

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**19.2**	**29.9**	**28.4**	**23.0**	**17.3**	**13.0**	**14.0**
Change from FY 2022 Budget Request			**-1.5**				
Percent change from FY 2022 Budget Request			**-5.0%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



Marshall Grazing Incidence X-ray Spectrometer (MaGIXS) instrument design, pictured above, drives technology development in alignment strategies and High-Resolution X-ray Optics.

The future success of Heliophysics depends on the ability to produce novel and transformative technologies, capabilities, and mission concepts. The Heliophysics Technology Program will strategically invest in the development and demonstration of instruments and technologies to enable infusion into future missions. Investments in new technologies will enable previously infeasible science investigations; improve existing measurement capabilities; reduce the cost, risk, and/or development times for Heliophysics science instruments and advanced space missions of the future; and yield applications benefits to the broader economy in areas of strategic importance such as space weather.

The Heliophysics Technology Program includes elements which are competitively selected through the NASA ROSES solicitation: Heliophysics Technology and Instrument Development for Science (HTIDeS) and Heliophysics Flight Opportunities Studies (HFOS). The program also includes technology demonstration missions: Solar Cruiser mission of opportunity and the Magnetometers for Innovation and Capability (MAGIC).

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

HELIOPHYSICS TECHNOLOGY

ACHIEVEMENTS IN FY 2021

NASA competitively solicited, selected, and matured technology efforts through the HTIDeS element. In FY 2021 HTIDeS managed 64 technology projects and advanced each of these technologies by one or more Technical Readiness Levels (TRL). The funded HTIDeS technology projects involved 160 students from across the Nation. There is an increase in selection of transformational (i.e., high risk/high reward) projects. One of the success stories is the advancement of technologies through HTIDeS leading to the Marshall Grazing Incidence X-ray Spectrometer (MaGIXS) instrument, which flew successfully on a sounding rocket instrument on July 30, 2021. MaGIXS achieved its goal of acquiring the first-ever high-resolution spectrally and spatially resolved X-ray observations of the solar atmosphere in the soft X-ray wavelength range.

MAGIC continued work in Phase B and completed its Single Design Review.

The Solar Cruiser technology demonstration mission of opportunity continued formulation activities in Phase B.

WORK IN PROGRESS IN FY 2022

NASA will expand the HTIDeS solicitation to solicit more cutting-edge technologies. The FY 2022 HTIDeS solicitation will also include Space Working Environment technologies to address the need for technologies that detect and mitigate space environmental factors that affect science investigations.

The Solar Cruiser technology mission of opportunity will complete its Preliminary Design Review and will prepare for KDP-C.

The MAGIC technology demonstration will continue Phase B formulation activities. It will complete the Single Design Review (SDR) and proceed to Phase C.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

NASA will initiate a technology incubator program to advance promising technologies through maturation and demonstration, and to enable more purposeful technology infusion in future science missions. The maturation of technologies will be achieved either in ground-based facilities or through orbital and suborbital flight, in partnership with NASA centers and Government agencies.

NASA will also expand the Heliophysics technology community by developing a solicitation for proposals from non-Heliophysics technologists. The goal is to infuse technology ideas from other disciplines into the Heliophysics community to enhance innovation and advance future Heliophysics science.

MAGIC will complete its SDR.

The Solar Cruiser mission will continue work in Phase C toward development of flight hardware and complete the System Integration Review (SIR).

HELIOPHYSICS TECHNOLOGY

Program Elements

TECHNOLOGY ANALYSIS AND MISSION DESIGN (TAMD)

The TAMD project will invest in mission concept studies of novel and transformative applications of new technologies in future Heliophysics flight missions. This includes and expands on HFOS. This project also conducts periodic technology gap analyses and analyses of trends in technology development/advancement to identify gaps in Heliophysics technology. This will enable more focused solicitations in the Advanced Technology Development project.

ADVANCED TECHNOLOGY DEVELOPMENT (ATD)

The ATD project will invest in the development of critical and innovative new instruments, technologies, and novel and transformative capabilities to achieve significant progress toward the scientific and technical challenges in Heliophysics in the coming years. This includes and expands on HTIDeS. This project will also establish an incubator process for the most promising early TRL technologies to proactively nurture and advance these capabilities. This project includes direct funding for critical technologies identified through the gap analysis.

This project also includes the new Alternative Initiation of Technology Exploration (AITE) element to grow and diversify the Heliophysics technology development community. As a component of the HTIDeS element, AITE will solicit proposals from non-heliophysics technologists to collaborate with heliophysics scientists and apply their technologies in solving key Heliophysics Science questions. The goal is to tap into non-heliophysics technologists to solve Heliophysics Science questions.

TECHNOLOGY PATHFINDER (TP)

The TP project will advance technologies and instruments from a proof of concept to demonstration, maturing transformational technologies across the critical gap that resides between early-stage concepts and flight demonstration. Access to relevant flight demonstration environments will be achieved using ground-based facilities, flight-based platforms such as orbital SmallSats and CubeSats, and suborbital balloons and rockets through the Heliophysics Flight Opportunities for Research (HFORT) program element.

This project will also utilize rideshare opportunities for flight demonstration of more mature technologies to increase the potential for future infusion into larger Heliophysics missions.

MAGNETOMETERS FOR INNOVATION AND CAPABILITY (MAGIC)

MAGIC is a five-year project to develop key fluxgate magnetometer technology and to design, build, test, and fly a next-generation spaceflight fluxgate. The MAGIC tool suite is designed to process magnetograms for use in models which require Solar Magnetic field as input and will fill a critical gap in technologies for Heliophysics science measurements.

MAGIC is a technology demonstration payload on the TRACERS mission, to be launched in 2024.

HELIOPHYSICS TECHNOLOGY

SOLAR CRUISER

Solar Cruiser, a SmallSat mission to be launched with IMAP in 2025, is a technology demonstration mission of opportunity. Solar Cruiser will demonstrate a 1,700 square meter solar sail. If successfully demonstrated, such solar sails can be used to propel spacecraft and can enable spacecraft to collect observations from novel vantage points that are difficult to reach and sustain. Specifically, Solar Cruiser will maintain a position sunward of Lagrange point L1—the position where Earth's and the Sun's gravity are balanced along the Sun-Earth-Line. Solar Cruiser will also demonstrate technologies that will enable future missions to improve space-weather monitoring, prediction, and science.

Program Schedule

Date	Significant Event
Q2 FY 2022	MAGIC KDP-C
Q2 FY 2022	ROSES-2021 HTIDeS and HFOS selections
Q2 FY 2022	ROSES 2022 HTIDeS and HFOS Solicitations released
Q3 FY 2022	Solar Cruiser PDR
Q3 FY 2022	Solar Cruiser KDP-C
Q4 FY 2022	MAGIC SDR
Q1 FY 2023	MAGIC KDP-D
Q2 FY 2023	ROSES-2022 HTIDeS and HFOS selections
Q2 FY 2023	ROSES-2023 HTIDeS and HFOS solicitations released
Q1 FY 2024	Solar Cruiser KDP-D
Q2 FY 2024	ROSES-2023 HTIDeS and HFOS selections
Q2 FY 2024	ROSES-2024 HTIDeS and HFOS solicitations released
Q4 FY 2024	MAGIC KDP-E, FRR
Q2 FY 2024	Solar Cruiser FRR
Q2 FY 2025	Solar Cruiser KDP-E

HELIOPHYSICS TECHNOLOGY

Program Management & Commitments

NASA will assign program management responsibility to the Heliophysics Strategic Technology Office. The Agency will evaluate Center proposals for the establishment of this office and make a selection in FY 2022.

Program Element	Provider
Technology Analysis & Mission Design (TAMD)	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): None
Technology Development (TD)	Provider: Various Lead Center: HQ Performing Center(s): TBD Cost Share Partner(s): None
Technology Pathfinder (TP)	Provider: Various Lead Center: HQ Performing Center(s): TBD Cost Share Partner(s): None
Solar Cruiser	Provider: MSFC Lead Center: GSFC Performing Center(s): MSFC Cost Share Partner(s): None
MAGIC	Provider: University of Iowa Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): None

Acquisition Strategy

NASA primarily procures tasks through full and open competition, such as the ROSES announcements. The solicitation of technology investments is competitive and selected from NASA Centers, industry, and academia as well as other Government agencies, Federally Funded Research and Development Centers, and nonprofit organizations. NASA may directly fund critical technologies identified through a gap analysis.

MAJOR CONTRACTS/AWARDS

None.

HELIOPHYSICS TECHNOLOGY

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Relevance	National Academies of Science, Committee for Solar and Space Physics (CSSP)	2022	Independent assessment of targeted technology development priorities for Heliophysics Technology	TBD	2024

BIOLOGICAL AND PHYSICAL SCIENCES

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**79.1**	**109.1**	**100.4**	**102.1**	**104.1**	**106.2**	**108.4**

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Biological and Physical Sciences

BIOLOGICAL AND PHYSICAL SCIENCES

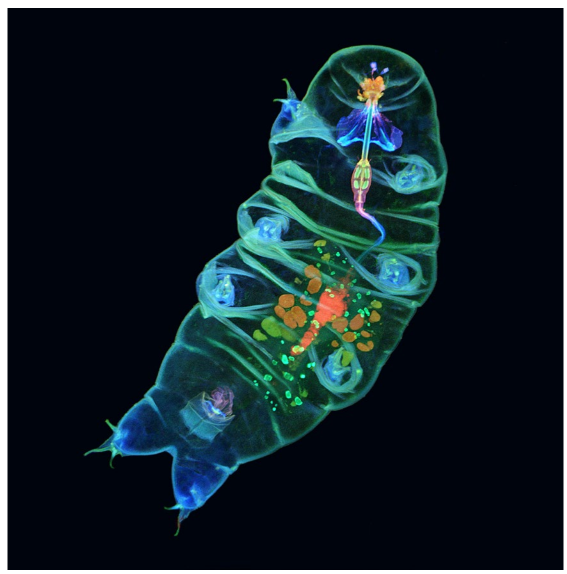
FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**79.1**	**109.1**	**100.4**	**102.1**	**104.1**	**106.2**	**108.4**
Change from FY 2022 Budget Request			**-8.7**				
Percent change from FY 2022 Budget Request			**-8.0%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

NASA's Biological and Physical Sciences (BPS) division conducts research in space to obtain critical insights into how biological and physical systems function in ways not possible on Earth. The unique, extreme conditions found in space, such as altered gravity and deep-space radiation, provide scientists with opportunities to probe biological and physical systems that cannot be done on Earth. The resulting knowledge can lead to new and transformative scientific discoveries and technological advancements that not only support NASA's deep-space missions, but also benefit life on Earth.



The tardigrade (shown above), a microscopic animal that is able to survive in some of the most extreme environments, is being studied aboard the International Space Station (ISS). Understanding how they tolerate extreme environments can better guide research into protecting humans from the stresses of long-duration space travel.

To achieve compelling, transformative science, BPS implements a focused research portfolio with two areas of emphasis:

- Quantum Science: Pushing the frontiers of the fundamental science of unique states of quantum matter.
- Thriving In DEep Space (TIDES): Pioneering fundamental biological discoveries that enable humans to go farther and stay longer in space, as well as contribute to biomedical and agricultural advancements on Earth.

BPS investigations are conducted via competitively awarded research grants to scientists at universities, research institutions across the country, and NASA centers. BPS develops critical equipment and processes to support new experiments and shares research results with academia, commercial industry, and other government agencies.

The division facilitates and oversees collaborations between a wide range of agencies, including the National Institutes of Health (NIH), National Center for Advancing Translational Sciences (NCATS), NIH's National Institute of Allergy and Infectious Diseases (NIAID), NIH's National Cancer Institute

Division of Cancer Treatment and Diagnosis, Biomedical Advanced Research and Development Authority (BARDA), and the Food and Drug Administration (FDA).

BPS also works closely with international partners, which include the European Space Agency (ESA), Canadian Space Agency (CSA), French Space Agency (CNES), Japanese Aerospace Exploration Agency (JAXA), German Aerospace Center (DLR), Roscosmos State Corporation for Space Activities, (ROSCOSMOS), Italian Space Agency (ASI), and Institute for Biomedical Problems of the Russian Academy of Sciences (IMBP RAS).

BPS research has been guided by priorities recommended by the 2011 Decadal Survey. In the summer of 2023, BPS expects to receive the scientific community's research priorities for the decade ahead with the issuance of the 2023-2032 Decadal Survey on Biological and Physical Sciences Research in Space.

EXPLANATION OF MAJOR CHANGES IN FY 2023

The level of support for Space Biology is at a similar level as in prior years. Compared to the plan proposed in the FY 2022 request, NASA will delay expanding Space Biology investigations and developing a facility to conduct Soft Matter research in low-Earth orbit. NASA will reassess its BPS portfolio once the results of the 2023 Decadal Survey are available.

ACHIEVEMENTS IN FY 2021

Quantum Science: Pioneering Quantum Science

Investigators using the Cold Atom Lab (CAL) produced two significant results in FY 2021. One team formed atomic bubbles in shell-shaped traps. Due to gravity, these bubbles cannot be formed on Earth. These results will enable further investigations studying superfluid flow and the onset of turbulence and could enable investigations that reveal signatures of new physics. Another team created, at 100 picokelvin, the coldest atomic gas ever demonstrated in space. These results will enable high precision space-based quantum instrumentation using atomic interferometers and pave the way for the next generation of even more sophisticated space-based quantum research facilities.

Thriving in Deep Space (TIDES): Understanding Muscle Loss

Astronauts lose muscle mass during space travel; fortunately, nematode worms -- multicellular animals with smooth, unsegmented bodies -- are an excellent cost-effective model for studying muscle loss in humans. The Micro-16 experiment completed operation on the ISS and returned samples currently undergoing analysis. This experiment examines the physiological mechanisms that may cause muscle loss through the study of worms in space. This will advance knowledge of muscle mechanics and physiological performance affected by the spaceflight environment. Findings will be used to address risks for human performance deterioration and to develop new countermeasure strategies for maintaining muscle strength. This study will also increase the understanding of mechanisms that may be associated with aging, bed rest, and disease on Earth.

Thriving in Deep Space (TIDES): Gardening in the Galaxy

NASA researchers conducted a series of plant biology experiments on the International Space Station (ISS) to investigate how plants respond and adapt to the space environment to enable space crop production. Researchers completed the Advanced Plant Experiments (APEX-08) and studied the effects of environmental conditions on plant growth to identify novel genetic engineering strategies for improving plant adaptation in space and on Earth.

The Plant Habit (PH-02) experiment investigated the effects of spaceflight on radishes, a nutritious alternative to leafy greens. This knowledge will be essential for the transition from Earth-bound cultivation of plants to growth conditions in space, and to enable the development of nutritionally valuable food crops that can be reliably grown in a space environment. BPS is also collaborating with the Human Research Program (HRP) to study both the psychological benefits to humans of having plants in space, as well as ways to improve the taste of space-grown food on the space station.

Thriving in Deep Space (TIDES): Analyzing Bone Tissue Responses in Space

Tissue degeneration and failure of tissue to regenerate in microgravity, as on Earth, is a concern for long-duration spaceflight. Rodent Research 10 (RR-10) examined the genetic ties in mice to the regeneration "healer" and development of new bone tissue in microgravity on ISS. The RR-10 science is essential to Space Biology and the TIDES initiative towards enabling deep-space exploration.

Soft Matter: Deepening our Understanding of Soft Matter

A colloid is a mixture in which one substance can be divided into minute particles dispersed throughout a liquid, such as a gel, sol, or emulsion. Colloid investigations form a key part of BPS's Soft Matter portfolio because not only can they be used to develop novel materials, but they also allow us to study self-assembly, crystallization, and processes that follow non-equilibrium thermodynamics. During FY 2021, NASA completed the Advanced Colloids Experiment (ACE) series of experiments using the Light Microscopy Module (LMM) in the Fluids Integrated Rack (FIR). In FY 2021, these investigations produced the first realization of a colloidal face-centered cubic crystal and studied the dynamics of three-dimensional chains that parallel protein folding dynamics.

2011 Decadal Survey Priority Investigations: Establishing a Theoretical Basis for Spacecraft Fire Safety

The Burning Rate Emulator (BRE) investigation revealed that while materials burn more easily in microgravity, the burning rate is reduced. Using the flight data, principal investigators (PIs) developed and published a theoretical foundation for microgravity flame behavior. Future spacecraft and vehicle designers can use this theory to minimize fire risk during exploration missions.

2011 Decadal Survey Priority Investigations: Advancing Scientific Study of Diseases

Understanding how fibrils form can aid the development of preventative treatments for neurodegenerative disorders and can also help improve the safety of drug manufacturing processes and delivery protocols. The Ring-Sheared Drop (RSD) investigation facilitates the study of amyloidogenesis (the formation of amyloid fibrils) and flow in a microgravity environment. Amyloid fibrils are abnormal protein deposits linked to various diseases in the human body, such as Alzheimer’s. During FY 2021, NASA completed 6 of the 8 planned RSD samples and returned them to the PI for analysis.

WORK IN PROGRESS IN FY 2022

Quantum Science: Exploring the Fifth State of Matter

NASA’s Cold Atom Lab is a first-of-its-kind physics laboratory operating in Earth orbit. About the size of a mini fridge, it hosts multiple experiments that explore the fundamental nature of atoms by cooling them down to nearly absolute zero (the coldest temperature matter can reach). The ultracold atoms provide a window into the quantum realm, where matter exhibits strange behaviors that underpin many modern technologies. In FY 2022, the CAL will characterize the space-based performance of a new microwave source to improve the cooling and manipulation of quantum gases and will begin to use it to study interacting atoms in spin mixtures and the physics of atom lasers in space.

Thriving In Deep Space (TIDES): Studying the Combined Effects of Deep-Space Stressors on Humans/Animals

Bio-Expt-1 will launch aboard the Artemis I mission. NASA completed the full design and validation of the experiment and hardware in FY 2021. The final science preparation and integration with the vehicle will occur prior to launch. This experiment will analyze the impacts of deep-space radiation on biological systems and will contain the first biological experiments to be conducted beyond the Van Allen Belts since the Apollo missions. The four investigations will study the impact of deep-space radiation and microgravity on seeds, yeast, fungus, and algae.

A joint study collaboration between BPS, NASA's HRP, and an international partner will enable researchers (Mouse Habitat-8 and several complementary ground studies) to directly compare mice exposed to microgravity in space with those subjected to simulated gravity in space using a centrifuge. This will allow scientists to uncover which physiological changes are due to microgravity alone versus the ones that are due to other spaceflight factors such as radiation.

In FY 2022, reviewers will select proposals and begin work on a joint solicitation on 3D Tissues and Microphysiological Systems. This solicitation is in partnership with the NIH, FDA, BARDA, and NASA to extend the longevity of these advanced in vitro platforms. This will allow NASA to study the effect of spaceflight stressors, such as combined radiation and microgravity using human analog models to support astronaut healthcare for long-duration deep-space exploration missions. The extended tissue chip lifespan would enable researchers to assess the effects of acute and chronic stressors over longer periods of time.

Thriving In Deep Space (TIDES): Gardening in the Galaxy

NASA researchers continue to conduct a series of plant biology experiments on the ISS. Advanced Plant Experiments (APEX-07) will be performed in FY 2022 and will analyze the genetic plant responses in both the shoot and root growth when exposed to spaceflight stresses.

Thriving In Deep Space (TIDES): Studying Microbes

In closed-loop habitats (such as aboard the space station), microbes may pose challenges through virulence and contamination, such as biofilms in water supply and ventilation systems. NASA plans to execute the MVP Cell-02 investigation, which seeks to understand how these organisms adapt to the space environment so that countermeasures can be developed to protect human/animal/plant life in space. Spaceflight environment promotes microbial stress survival. Microbial Tracking-3 is identifying bacteria and fungi in the space station environment and monitoring them for potential future impacts to humans and/or resistance to antibiotics.

2011 Decadal Survey Priority Investigations: Studying Combustion in Space

Fire can be a catastrophic hazard for crewed spacecraft. During FY 2022, NASA researchers plan to install and operate the Solid Fuel Ignition and Extinction (SoFIE) hardware in the Combustion Integrated Rack (CIR), which is expected to help identify -- and develop countermeasures against -- unsafe conditions. The Growth and Extinction Limit (GEL) will be the first investigation; it will study flame growth, decay, and extinction over the surface of a non-flat, thick solid.

2011 Decadal Survey Priority Investigations: Improving Thermal Management Systems for Space Exploration

Long-duration human exploration space missions will demand additional power and heat dissipation requirements compared to current space missions. To reduce size and weight, the transition from single-phase (liquid only) to more efficient two-phase (liquid and gas) thermal management systems may be necessary. Boiling and condensation data in microgravity are needed to validate numerical simulation tools that will be used to design these new thermal management systems. To obtain that data, NASA plans to install and operate the Flow Boiling and Condensation Experiment (FBCE) within the Fluids Integration Rack on the ISS.

2011 Decadal Survey Priority Investigations: Generating Data for Semiconductor Fabrication

Semiconductors are used in the manufacture of various electronic devices. While a critical industry, semiconductor fabrication still suffers from defects due to buoyancy-driven flows. These defects reduce production yield, as chips with flaws must be discarded. In FY 2022, NASA will operate the Growth of Ternary Compound Semiconductors investigation in the ESA Materials Science Research Rack (MSRR) to understand how gravity contributes to forming defects in these crystals.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

Quantum Science

CAL will extend the use of quantum gases to form mixtures of rubidium and potassium, thus enabling a space-based test of Einstein's Equivalence Principle, which states that the effect of gravity upon an object is independent of the composition, location, and velocity of the object. CAL also enables studies of purely quantum mechanical few-body physics.

Thriving in Deep Space (TIDES)

During FY 2023, BPS will begin development of a beyond low Earth orbit multicellular research capability and expand ground test capabilities to maximize the scientific return of flight missions.

2011 Decadal Survey Priority Investigations: Thermal Management for Space Exploration

Heat removal by condensation is slowed when the liquid fluid films coat the condensing surface. This effect is more problematic in reduced gravity because there is no force to drain the liquid from the surface. In FY 2023, NASA will study microgravity heat removal via condensation for a flow configuration.

2011 Decadal Survey Priority Investigations: Studying Combustion in Space

Because scientists do not understand the full range of ignition and extinction conditions for solid fuels in microgravity, NASA will conduct an investigation to map out these events as a function of flow, oxygen levels, and external radiant heat flux. These data will also guide testing procedures for conditions beyond low Earth orbit.

BIOLOGICAL AND PHYSICAL SCIENCES

Program Elements

BPS PROGRAM MANAGEMENT

This project funds BPS's institutional and crosscutting activities including: National Academies studies, proposal peer review processes, printing and graphics, information technology, the NASA Postdoctoral Fellowship program, National Research and Educational Support Services (NRESS), working group support, independent assessment studies, communications, and other administrative tasks.

SPACE BIOLOGY

The main objective of the Space Biology project is to build a better understanding of how spaceflight affects living systems in spacecraft (e.g., ISS) or in ground-based experiments that mimic aspects of spaceflight, and to prepare for future human exploration missions far from Earth. The experiments researchers conduct on these platforms examine how plants, microbes, and animals adjust or adapt to living in space. Researchers study the processes of metabolism, growth, stress response, physiology, and development. The program studies how organisms repair cellular damage and protect themselves from infection and disease in conditions of microgravity while being exposed to space radiation—and across the spectrum of biological organization, from molecules to cells, from tissues to organs, and from systems to whole organisms, to communities of microorganisms. These studies often reveal new insights into biological functions that would be difficult or impossible to obtain only through Earth-based experiments.

In addition to providing useful information on how living organisms adapt to spaceflight, the discoveries NASA researchers make in space have significant implications for life on Earth. Space Biology's research into the virulence of pathogens in space, loss of bone density, and the changes in the growth of plants can impact the development of drugs that promote wound healing or tissue regeneration. This research will also inform treatments designed to counter osteoporosis on Earth, and high-tech fertilizers that increase crop yield.

BPS is committed to open science via comprehensive space-related omics databases where users can upload, download, share, store, and analyze spaceflight and spaceflight-relevant data from experiments using model organisms. Omics refers to a collection of biological classes of study, such as genomics, transcriptomics, and others that focuses on the collective characterization and quantification of pools of biological molecules that translate into the structure, function, and dynamics of an organism or organisms. BPS's databases include: GeneLab, the Life Sciences Data Archive, and Ames Life Sciences Data Archive.

PHYSICAL SCIENCES

Physical Sciences research makes contributions in two distinct ways. The first, basic research, investigates physical phenomena in the absence of gravity and fundamental laws of the universe, and provides transformative understanding. Quantum Science is the primary focus area for basic research, which takes advantage of the ability to "float" assemblies of ultra-cold atoms in microgravity for long times with extremely gentle forces- something that cannot be done on Earth.

The second type of contribution is applied research, which contributes to the basic understanding of underlying space exploration technologies such as power generation and storage, space propulsion, life support systems, and environmental monitoring and control, leading to transformational capabilities for exploration. The Combustion Science, Fluid Physics, and Materials Science research is in this category. In these applied areas, microgravity is both a scientific tool but also a major challenge for engineering systems that must operate in space. The scientific advances in these areas can enable transformative advances in spacecraft systems.

The data acquired from these investigations are stored in NASA's Physical Sciences Informatics system (PSI) and is available to the public.

Program Schedule

Date	Significant Event
Q1 FY 2022	Annual Space Biology NRA solicitation release
Q1 FY 2022	Joint Solicitation on 3D Tissues and Microphysiological Systems selection
Q2 FY 2022	Joint Solicitation on 3D Tissues and Microphysiological Systems awards
Q2 FY 2022	Physical Sciences Informatics proposals due
Q3 FY 2022	Quantum Science solicitation release
Q4 FY 2022	Quantum Science proposals due
Q4 FY 2022	Annual Space Biology NRA selection
Q4 FY 2022	Annual Physical Sciences Informatics selection
Q1 FY 2023	Annual Space Biology NRA solicitation release
Q2 FY 2023	Quantum Sciences solicitation selection
Q2 FY 2023	Physical Sciences Informatics proposals due
Q3 FY 2023	Quantum Sciences solicitation release
Q4 FY 2023	Quantum Science proposals due
Q4 FY 2023	Physical Sciences Informatics solicitation selection
Q4 FY 2023	Annual Space Biology NRA solicitation selection

Program Management & Commitments

The Space Operations Mission Directorate (SOMD), through the ISS Program Vehicle Office, will retain responsibility for the sustainment, maintenance, and operation of multi-user hardware that supports the biological and physical sciences research portfolio through at least FY 2024. Additionally, SOMD, through the ISS Program Research Integration Office, will retain responsibility to fund the Mission Integration and Operations (M&IO) work for BPS investigations through at least FY 2024. NASA will reassess this support as commercial low Earth orbit capabilities evolve.

BIOLOGICAL AND PHYSICAL SCIENCES

Program Element	Provider
Space Biology (animal biology, microbiology, and open science)	Provider: Various Lead Center: Ames Research Center (ARC) Performing Center(s): ARC, Kennedy Space Center (KSC) Cost Share Partner(s): N/A
Space Biology (plant biology, cell biology, molecular biology, and plant microbiology)	Provider: Various Lead Center: KSC Performing Center(s): ARC, KSC Cost Share Partner(s): N/A
Physical Sciences (soft matter, fluids, combustion, Fluids Integrated Rack, and Combustion Integrated Rack)	Provider: Various Lead Center: Glenn Research Center (GRC) Cost Share Partner(s): N/A
Physical Sciences (materials and Materials Science Research Rack)	Provider: Various Lead Center: MSFC Cost Share Partner(s): N/A
Physical Sciences (quantum research, fundamental physics, and Cold Atom Lab)	Provider: Various Lead Center: JPL Cost Share Partner(s): N/A

Acquisition Strategy

BPS research is competitively selected via NASA Research Announcements (NRAs). Once selected, the principal investigator is paired with a field center and a commercial partner to facilitate the implementation of the project.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Independent Review Board (IRB)	Oct 2021	LEIA System Requirements and Preliminary Design Review	Successful	Mar 2022
Performance	IRB	Mar 2022	Operational Readiness Review: SoFIE GEL	TBD	May 2022
Performance	IRB	May 2022	System Acceptance Review for FAMIS	TBD	May 2022
Performance	IRB	May 2022	Critical Design Review: Electrohydro-Dynamics	TBD	May 2022
Performance	IRB	May 2022	LEIA Critical Design Review	TBD	Aug 2022

BIOLOGICAL AND PHYSICAL SCIENCES

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	IRB	Aug 2022	Critical Design Review: Diffusion in Germanium and Silicon	TBD	Nov 2022
Performance	IRB	Nov 2022	LEIA PRISM Delta CDR	TBD	Dec 2022
Performance	IRB	Dec 2022	System Acceptance Review for FBCE Condensation Module-Heat Transfer	TBD	Apr 2023
Performance	IRB	Apr 2023	LEIA Systems Integration Review	TBD	2023
Relevance	National Academies of Science	2023	Decadal survey review of BPS research priorities	TBD	2033

AERONAUTICS

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Airspace Operations and Safety Program	132.0	147.4	**156.2**	159.0	164.2	183.6	196.8
Advanced Air Vehicles Program	211.4	243.7	**253.2**	269.5	287.2	270.5	235.9
Integrated Aviation Systems Program	238.7	258.6	**288.9**	287.1	284.0	296.4	322.3
Transformative Aero Concepts Program	129.7	148.0	**155.9**	158.0	158.0	163.0	176.6
Aerosciences Evaluation and Test Capabilities	116.9	117.0	**117.3**	117.3	117.3	117.3	119.9
Total Budget	**828.7**	**914.8**	**971.5**	**990.9**	**1,010.7**	**1,030.9**	**1,051.5**

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

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AERONAUTICS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Airspace Operations and Safety Program	132.0	147.4	**156.2**	159.0	164.2	183.6	196.8
Advanced Air Vehicles Program	211.4	243.7	**253.2**	269.5	287.2	270.5	235.9
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Transformative Aero Concepts Program	129.7	148.0	**155.9**	158.0	158.0	163.0	176.6
Aerosciences Evaluation and Test Capabilities	116.9	117.0	**117.3**	117.3	117.3	117.3	119.9
Total Budget	**828.7**	**914.8**	**971.5**	**990.9**	**1,010.7**	**1,030.9**	**1,051.5**
Change from FY 2022 Budget Request			**56.7**				
Percent change from FY 2022 Budget Request			**6.2%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

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NASA will demonstrate high-risk, high-reward technologies critical to the United States' achieving sustainable aviation goals.

The first "A" in NASA stands for "Aeronautics." NASA Aeronautics explores technologies that reduce aircraft noise and fuel use, get you from gate-to-gate safely and on time, and transform aviation into an economic engine at all altitudes. Each of these transformations are taking place grounded in a mindset of green aviation and economic growth. Aeronautics researchers, engineers, and pilots use world-class NASA facilities to maintain U.S. global leadership in aviation safety, efficiency, and technological innovation.

NASA Aeronautics directly benefits an aviation sector that annually generates more than $1.8 trillion of total U.S. economic activity[1] and contributes the largest positive trade balance of any U.S. manufacturing sector totaling nearly $78 billion.[2] The aviation sector supports more than 10.9 million direct and indirect jobs, including more than one million high-quality manufacturing jobs. In 2019, U.S. airlines carried 926 million passengers and 21.3 billion tons of cargo.[3] Beginning in 2020, the COVID pandemic has had a dramatic impact on the aviation sector, with sharp reductions in air travel and

[1] *"The Economic Impact of Civil Aviation on the U.S. Economy," Federal Aviation Administration, January 2020*
[2] *"Leading Indicators for the U.S. Aerospace Industry," International Trade Administration, March 15, 2019*
[3] *"Preliminary Estimated Full Year 2019 and December 2019 U.S. Airline Traffic Data," U.S. Bureau of Transportation Statistics, April 30, 2020*

associated demand for new aircraft and engines. These trends have reversed as business and leisure travel markets have begun to recover, although full industry recovery to pre-COVID levels is not expected until at least 2023. In the meantime, NASA continues to focus on advancing aviation technology to meet this anticipated demand once it returns in full.

Four Transformations for Sustainability, Greater Mobility, and Economic Growth

With the FY 2023 budget, NASA is leading the transformation of aviation in several ways:

- Locally – through Advanced Air Mobility (AAM), Unmanned Aircraft Systems (UAS), and use of electric Vertical and Short Takeoff and Landing vehicles, NASA is working to transform the way people and goods move through the air transportation system. NASA is rallying emerging markets to tackle the challenges of creating an air transportation system featuring all-electric, highly automated or autonomous, efficient, and safe systems operating over the most rural countryside to the densest, skyscraper-filled urban environment. The FY 2023 budget funds NASA's AAM mission, which aims to ensure U.S. leadership in an emerging aviation market that studies have projected to generate an annual market value of $115 billion by 2035. The AAM mission will collaborate with industry to mature system concepts and technologies for safe operations. NASA will complete the first in a series of four National Campaign demonstrations by industry of their vehicles and airspace management technologies. The Airspace Operations and Safety (AOSP), Advanced Air Vehicles (AAVP), and Integrated Aviation Systems (IASP) programs will execute NASA's AAM mission.
- Across the nation – NASA is enabling transformative improvements in the efficiency of commercial aviation, with particular focus on the single aisle fleet (Boeing 737-size) through developing and demonstrating integrated electric propulsion in small to large aircraft, advanced materials, advanced propulsion systems, and new ways to design and build aircraft. The FY 2023 budget funds NASA's Sustainable Flight National Partnership (SFNP) to accomplish the aviation community's aggressive

sustainability agenda. Through advanced vehicle technologies, efficient airline operations, and sustainable aviation fuels, collectively we are focused on reducing carbon emissions from aviation by 50 percent by 2050, compared to 2005, and achieving net-zero aviation emissions by 2060. The SFNP will demonstrate the first-ever high-power hybrid electric propulsion system for large transport aircraft, ultra-high efficiency long and slender wings, advanced composite structures and manufacturing, and advanced engine technologies developed from NASA-industry innovation. The SFNP's centerpiece will be a large-scale sustainable flight demonstrator ("X-plane") to validate integrated systems and their benefits. NASA will complete the activities and projects by the late 2020's in order to transition new tools, technologies, and procedures into the next generation of large commercial aircraft. The AAVP, IASP, and AOSP execute NASA's SFNP activities.

- Globally – NASA is working to sustainably connect the world through high-speed commercial flight. NASA is removing barriers to commercial supersonic flight over land by demonstrating how to reduce sonic boom impacts, tackling the next challenges in local noise and investigating the potential of even higher-speed flight. The FY 2023 budget funds NASA's Low-Boom Flight Demonstration (LBFD) mission to enable U.S. industry to lead the development of a new commercial supersonic market. Currently there exists a global prohibition on commercial supersonic flight over land that has resulted from concerns about sonic boom impacts. NASA has developed guidelines for supersonic vehicle design that, when followed, significantly reduce the annoyance factors associated with sonic booms. NASA will build and fly a supersonic X-plane that has been designed using these guidelines over a diverse set of communities, collect the noise and community response data, and provide the data to U.S. and international regulators. These data will be used by the domestic and global regulatory communities to reassess the current commercial supersonic flight over land prohibition. The AAVP and IASP execute the LBFD mission.
- System wide – NASA is transforming the efficiency and safety of the entire global aviation system through future airspace tools and system design that supports a transformed airspace system that is safe and secure, supports all these new vehicles, and is less harmful to the environment. NASA, along with industry stakeholders, is developing a long-term future airspace vision called Sky for All with a horizon of 2045.

To ensure that research focuses on enabling this aviation transformation, NASA's Aeronautics Research Mission Directorate (ARMD) guides its efforts with a strategic implementation plan. The plan lays out NASA's approach to addressing the three key drivers of aviation transformation: the growing demand for global air mobility, energy efficiency and environmental sustainability, and the opportunity for convergence between traditional aeronautical disciplines and technology advances in information technology, communications, energy, and other rapidly evolving technologies. The strategic implementation plan identifies six research thrusts to comprehensively address the three key drivers.

Thrust 1: Safe, Efficient Growth in Global Operations

The Nation will need a modernized air transportation system with much greater capacity and operational efficiency, while maintaining safety. ARMD will contribute specific research and technology to support the Federal Aviation Administration's (FAA) transformation of the National Airspace System (NAS) to accommodate more diverse vehicles and increasingly complex operations in a safe and affordable manner. ARMD will work with the emerging Advanced Air Mobility ecosystem, developing concepts to enable a safe, scalable system for the growth of this new transportation sector. ARMD is working with the community to create a "Sky for All" vision of airspace management capabilities needed by 2045 with a service-based architecture, digital backbone, and artificial intelligence.

Thrust 2: Innovation in Commercial Supersonic Aircraft

The U.S. aviation industry has an opportunity to lead the development of a new commercial supersonic transcontinental and intercontinental aircraft that will generate major economic and societal benefits. ARMD will build and fly the X-59 aircraft that will demonstrate quiet supersonic flight and provide the data needed by regulatory agencies to reassess the regulations that currently ban overland commercial supersonic flight. Since overcoming these barriers involves modifications to regulations and certification standards, ARMD will conduct its research in cooperation with the FAA, International Civil Aviation Organization, and other aviation regulatory agencies. ARMD will also focus research on groundbreaking technologies that overcome barriers to supersonic flight such as reducing the environmental impact and improving economic efficiencies.

Thrust 3: Ultra-Efficient Subsonic Transports

The U.S. aviation industry faces increasing global competition in the subsonic commercial aircraft market, which represents the largest segment of the industry. To remain the global leader, the U.S. aviation industry strives for competitive advantages in aircraft efficiency, noise, and emissions. ARMD seeks to enable substantial efficiency gains along with a fundamental shift to innovative alternative energy-based propulsion systems through the electrification of aircraft propulsion in combination with sustainable alternative jet fuels. ARMD also is working to enable substantial reductions in time and cost to market of aircraft through advanced materials, structures, and manufacturing technologies and enhanced digitalization of the full aircraft life cycle. Under the NASA's Sustainable Flight National Partnership, ARMD will engage with U.S. industry to develop critical technologies including new aircraft configurations, hybrid electric propulsion, and advanced materials. These will enable revolutionary improvements in economic and environmental performance measures for the next generation of subsonic transport aircraft.

Thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles

In the coming years, the aviation community expects that new and cost-effective uses of aviation, including advanced Vertical Takeoff and Landing (VTOL) vehicles, could provide options for using air travel as part of daily activities. These new vehicles could provide unprecedented accessibility and shorter door to-door travel times compared to other modes of transportation. This mode of air travel will only be successful if the advanced VTOL aircraft provide acceptable levels of safety while reducing their environmental footprint – especially with regard to noise – compared to existing VTOL aircraft. ARMD will work across government, the transport industry, and academia to develop critical technologies to enable realization of extensive use of vertical lift vehicles for transportation services including new missions such as access to medical care and managing/fighting wildfires.

Thrust 5: In-Time System-Wide Safety Assurance

To support the projected growth in air traffic while continuing to improve air transportation safety, the U.S. will require the ability to identify and reduce safety risks quickly and accurately. ARMD will work with the FAA and industry to create advanced safety capabilities needed in the future air transportation system. These new capabilities will create a safety net that utilizes system-wide information to provide alerting and mitigation strategies in time to address emerging risks. In coordination with the FAA and industry, ARMD will develop and demonstrate new prognostic safety tools and concepts that will be needed to enable a successful AAM market.

Thrust 6: Assured Autonomy for Aviation Transformation

Ever-increasing levels of automation are improving the cost and efficiency of aviation and this trend will accelerate in the future. ARMD is leading the research and development of intelligent machine systems capable of operating in complex environments. To pave the way for increasingly autonomous airspace and vehicles, ARMD will explore new human-machine teaming, modeling, measuring, and testing that enable the effective evaluation of highly automated and autonomous systems in aviation applications. ARMD is developing autonomous systems to address critical challenges of the emerging AAM market and air traffic management. Additionally, ARMD is using and evaluating autonomous systems in upcoming AAM National Campaign demonstration series.

Cross-Cutting Capabilities

In addition to research that directly aligns with specific Strategic Thrusts, ARMD conducts foundational research on cross-cutting ideas and technologies that provides critical support across multiple Strategic Thrusts. This research enables a broad range of aeronautics and aerospace applications and explores opportunities for technology convergence from disparate technology areas.

ARMD's flight and ground test capabilities, complemented by high-fidelity computational simulation, enable rapid experimentation and feasibility demonstration of advanced concepts ranging from individual experiments, to proof-of-concept tests, to demonstration of integrated concepts embodying converging technologies. Relevant assets include flight research and support aircraft, wind tunnels, propulsion, acoustic, materials, and structures laboratories and test facilities, flight research and air traffic management simulators, airspace operations laboratories, high-end computing laboratories, and test support infrastructure. These facilities and capabilities will continue to evolve in support of the research necessary to support the Strategic Thrusts.

Hypersonic Capabilities

ARMD supports fundamental research on reducing the barriers to reusable hypersonic systems (speed of greater than Mach 5). ARMD's fundamental research will enable a broad spectrum of hypersonic systems and missions by advancing the core capabilities and critical technologies for hypersonic flight. The resulting technology advancements will be a benefit to national hypersonic programs both within NASA and in collaboration with the Department of Defense (DoD).

For more information on the Aeronautics strategic plan, go to: http://www.aeronautics.nasa.gov/strategic-plan.htm

EXPLANATION OF MAJOR CHANGES IN FY 2023

NASA increased funding for the Sustainable Flight Demonstrator (SFD) to ensure that this project will deliver results to industry and meet the goal of maturing critical technologies for next generation single-aisle aircraft. The SFD will be a large-scale integrated flight demonstration with objectives to reduce fuel burn, emissions, and noise. This project is the centerpiece of NASA's Sustainable Flight National Partnership.

NASA increased funding for the development of beyond next-generation zero-emissions aircraft concepts and technologies through the highly successful University Leadership Initiative.

AERONAUTICS

NASA will initiate a new project, Advanced Capabilities for Emergency Response Operations, aimed at improving aerial responses to wildfires. The project will leverage NASA-developed UAS traffic management capabilities, along with other NASA science and technology capabilities, and begin to develop an interagency concept of operations with other Federal, State, and local agencies.

NASA will transfer the AAM project from the Integrated Aviation Systems Program to the Airspace Operations and Safety Program. The AAM project relies on air traffic management capabilities developed by AOSP. Therefore, this realignment will maximize the synergies between the AAM project and AOSP's current projects, ATM Exploration, System Wide Safety, and Advanced Capabilities for Emergency Response Operations.

ACHIEVEMENTS IN FY 2021

Thrust 1: Safe, Efficient Growth in Global Operations

NASA successfully completed demonstrations of Integrated Arrival/Departure/Surface system capabilities in two busy airports, Dallas/Fort Worth and Charlotte. The new system significantly improved operational efficiency which reduces fuel burn and emissions. As an example of the benefits, at the Charlotte airport, over the period September 2017 to September 2021, this new capability saved over one million gallons of fuel and over 23 million pounds of CO2 emissions. These were the final demonstrations in a series of airspace technology demonstrations.

For additional Thrust 1 achievements, see the AOSP section.

Thrust 2: Innovation in Commercial Supersonic Aircraft

NASA made significant progress in the Low-Boom Flight Demonstration Mission. The Low-Boom Flight Demonstrator (X-59) aircraft began the final stages of assembly. During the year, the contractor integrated major components including the nose, vertical tail, forebody, wing, and stabilators and completed subsystem updates on the fuel and hydraulics systems. In preparation for the X-59 flight validation testing, NASA developed techniques to collect noise and performance data. NASA conducted a flight test of a nose mounted shock sensing probe on NASA's F-15 aircraft that will measure shock wave structure.

For additional Thrust 2 information, see the AAVP, IASP and LBFD.

Thrust 3: Ultra-Efficient Subsonic Transports

NASA initiated the Sustainable Flight National Partnership to further develop and mature technologies for the next generation commercial aircraft. NASA made progress in several SFNP activities:

The Electrified Powertrain Flight Demonstrations (EPFD) project awarded two major contracts for the ground and flight demonstrations of integrated megawatt-class powertrain systems for subsonic aircraft: General Electric Aviation (GE) of Cincinnati to flight test the CT7-9B turboshaft engines on a modified Saab 340B testbed and MagniX USA Inc of Redmond, Washington to demonstrate systems on a Dash 7-Combi. EPFD demonstrations will help to rapidly mature, and transition integrated electrified aircraft propulsion technologies for introduction into the global fleet in the 2030s.

NASA, through the Hybrid Thermally Efficient Core project, awarded six contracts to U.S. aircraft engine manufacturers to develop small core technologies that will advance the efficiency of turbofan engines. These efforts will culminate in an advanced core demonstration in 2026.

For additional Thrust 3 information, see the AAVP, IASP, and Transformative Aeronautics Concepts Program (TACP) sections.

Thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles

NASA conducted a series of public workshops co-sponsored by the FAA to examine aspects of crashworthiness of AAM vertical-lift vehicles. NASA's new focus area emphasizes occupant protection to address fundamental safety questions for AAM vehicles and provide information to standards organizations.

For additional Thrust 4 information, see the AAVP section.

Thrust 5: In-Time System-Wide Safety Assurance

NASA developed techniques that process vehicle operating performance data to predict system safety and evaluate potential mitigations. NASA demonstrated these predictive techniques for AAM vehicles. NASA evaluated the use of a tool to actively monitor components while in operation to constrain the behavior of machine learning-enabled system components. This evaluation will enable the FAA to develop requirements for certification of autonomous systems.

For additional Thrust 5 information, see the AOSP section.

Thrust 6: Assured Autonomy for Aviation Transformation

With industry collaboration, NASA successfully completed development testing for the AAM National Campaign (NC) that demonstrated maturity of key systems and infrastructure. In support of the NC test series, NASA developed airspace management capabilities to enable urban air mobility operations.

For additional Thrust 6 information, see the AOSP section.

Cross-Cutting Capabilities

NASA completed a Combustion and Emissions Analysis of Alternatives study specifically focused on combustion modeling of sustainable aviation fuels, which is a key component of NASA's Sustainable Flight National Partnership. The AAVP will use the study results to inform further investigation into reducing the time and costs associated with certifying sustainable aviation fuels. Additionally, working with industry, NASA has developed a capability to predict the impact of new alternative fuels which can save thousands of gallons of fuel and months of time during the fuel certification process by reducing or eliminating costly combustion tests.

For additional cross-cutting capabilities information, see the TACP and Aerosciences Evaluation and Test Capabilities sections.

Hypersonic Capabilities

Using calibrated mathematical models, NASA predicted hypersonic flight test performance that included a quantified level of uncertainty. NASA developed an approach to optimize a design, with quantified uncertainties, and then applied this approach to a turbine-based combined cycle propulsion component. These uncertainty quantification methods will be critical to future design and analysis efforts.

For additional hypersonic capabilities information, see the AAVP section.

WORK IN PROGRESS IN FY 2022

Thrust 1: Safe, Efficient Growth in Global Operations

After successfully completing the demonstrations of Integrated Arrival/Departure/Surface system capabilities, NASA formally closed out the Airspace Technology Development project. Data and tools developed by the project will be transitioned to industry and the FAA. Over the project's life, NASA transferred a comprehensive suite of tools that will improve aircraft arrival, surface management, and departure efficiencies.

For additional Thrust 1 achievements, see the AOSP section.

Thrust 2: Innovation in Commercial Supersonic Aircraft

NASA completed the final assembly and system checkouts of the X-59 aircraft and shipped the aircraft to Lockheed Martin's facility in Fort Worth, Texas for a ground proof loads test. After testing, NASA will return the aircraft to Palmdale, California for a series of ground tests including the ground vibration test, engine runs, and taxi tests. NASA will conduct a series of airworthiness and flight safety reviews of the aircraft in preparation for first flight in FY 2023.

In preparation for X-59 flight operations, NASA will deliver a validated F-15-based test capability that enables precise, near-field probing and airborne imaging of the shockwave structure. This capability ensures that the shockwave structure produced by the X-59 aircraft in flight is easily comparable with current simulations during the flight test campaign.

Thrust 3: Ultra-Efficient Subsonic Transports

NASA will begin the Sustainable Flight Demonstrator project. The SFD will be a large-scale integrated flight demonstration with objectives to reduce fuel burn, emissions, and noise. This project is the centerpiece of NASA's Sustainable Flight National Partnership.

NASA will conduct flight tests of the all-electric X-57 Maxwell aircraft. In conjunction with the flight tests, NASA will support the development of manufacturing standards for electrified aircraft systems to enable progress for U.S. companies to develop more electric aircraft.

Thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles

NASA will demonstrate improved computer-based tools for predicting and evaluating the noise and performance of AAM vehicle configurations. These efforts will benefit the AAM community by providing design tools and guidelines that will increase the likelihood that their new aircraft designs will meet noise goals before the development and construction of a full-scale vehicle.

Thrust 5: In-Time System-Wide Safety Assurance

NASA will evaluate the potential benefits of including non-traditional data sources (e.g., ground data, maintenance data, human performance data) together with traditional safety data to evaluate overall safety risk profiles. NASA will deliver draft evidence and recommendations to industry standards committees and safety and regulatory partners on the use of run-time monitoring for automated components and the robustness of remote operators as a backup in case of automation failure.

Thrust 6: Assured Autonomy for Aviation Transformation

NASA will engage with industry to develop and evaluate novel air traffic management capabilities for AAM vehicles in flight. These capabilities will undergo rigorous development and testing in a controlled environment before transitioning to field demonstrations.

Cross-Cutting Capabilities

NASA will complete feasibility assessments on two Convergent Aeronautics Solutions project activities: Scalable Traffic Management for Emergency Response Operations (STEReO) and Fit2Fly. The STEReO activity will create an UAS Traffic Management ecosystem that can reduce response times, scale aircraft operations, and provide operational resiliency to active changes during a disaster. The Fit2Fly activity will produce concepts to assure operators of commercial drone fleets that vehicles are able to fly using automated inspection and digital airworthiness certificates. This concept will create an auditable system determining whether aircraft have enough reliability to perform their intended missions.

Hypersonic Capabilities

NASA will conduct surface roughness experiments related to two sounding rocket flights by the Air Force Office of Scientific Research. Using ground test data and flight data as appropriate, NASA will study hypersonic boundary layer transition on complex, three-dimensional geometries, which will reduce vehicle-level uncertainty and maximize performance.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

Thrust 1: Safe, Efficient Growth in Global Operations

NASA will form a foundation for the development and use of advanced artificial intelligence and machine learning airspace services. This will be achieved by collaboratively demonstrating a prototype cloud-based digital information platform that improves the ability for operators to access and share airspace data.

Thrust 2: Innovation in Commercial Supersonic Aircraft

NASA will conduct the first flight of the X-59 aircraft and complete airworthiness flight testing in preparation for the community response testing. During the initial testing, NASA will gather ground level noise data to verify the acoustic characteristics of the aircraft. In preparation of the community flight tests, NASA will prepare test plans, develop procedures, and procure equipment.

Thrust 3: Ultra-Efficient Subsonic Transports

NASA will make progress in several Sustainable Flight National Partnership activities:

The two Electrified Powertrain Flight Demonstration industry teams will enter the development phase and work to a first flight in FY 2024.

In collaboration with industry, NASA will demonstrate a hybrid-electric powertrain for transport-class aircraft that has a total power of at least three times the nominal 260-kilowatt state-of-the-art. This demonstration will include the flight-weight and flight-like components required to bring the technology to flight. Further, the system will also meet safety requirements for fault management, redundancy, and power quality needed for use on commercial transports. In taking this approach, future transports will be able to use hybrid propulsion technologies for aircraft efficiency benefits.

NASA will award contracts for the demonstration of integrated core engine technologies in an environment that simulates flight conditions. This demonstration will show sufficient technical maturity that the demonstrated technologies may be considered for inclusion on next-generation aircraft engines.

NASA will award cooperative agreements for the preliminary design of full-scale aircraft components for future tests that will demonstrate structural performance and high-rate manufacturing technology.

NASA will award the contract for the Sustainable Flight Demonstrator and continue formulation of the project.

Thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles

NASA's vertical lift research into electric motor reliability, power quality, and noise will help enable the emerging AAM market. NASA will complete work on a validated set of computer-based analysis tools, including thermal modeling, to calculate the reliability of an electric motor design for AAM applications. NASA will provide the methodology to the industry community through publications. By working with the relevant SAE Standards Committee, NASA will contribute to defining technical standards for AAM power quality that will improve the reliability and safety of AAM vehicles. NASA will complete an electric motor noise model and incorporate it into publicly available acoustic prediction tools for use in improving the ability to predict the full spectrum of noise for AAM vehicles.

Thrust 5: In-Time System-Wide Safety Assurance

NASA will analyze aircraft and ground operations data from partners, flight tests, and simulations. The analysis will provide recommendations where NASA developed monitoring, assessment, and mitigation techniques which can be used in future aviation operations.

Thrust 6: Assured Autonomy for Aviation Transformation

NASA will advance the capability of airspace services necessary to enable AAM operations by working collaboratively with industry partners to identify, implement, and test community-based rules for pre-departure scheduling and strategic deconfliction services. NASA will demonstrate algorithms to analyze safety standards for systems that rely on untrusted components, used for increasingly autonomous aviation surface and drone flight operations.

NASA will initiate a new project, Advanced Capabilities for Emergency Response Operations, aimed at improving aerial responses to wildfires. The project will leverage NASA developed UAS traffic management capabilities and begin to develop an interagency concept of operations with other Federal, State, and local agencies.

Cross-Cutting Capabilities

NASA will complete acoustic perception-influenced validation experiments of multi-disciplinary design, analyses, and optimization in the Low Speed Aeroacoustic Wind Tunnel. NASA will use rapid aerodynamic modeling methods to develop a research aircraft and to baseline flight control laws.

NASA will complete two Convergent Aeronautics Solutions project activities: Solid-state additively manufactured batteries for enhanced energy, recharging, and safety; Sensor-based prognostics to avoid runaway reactions and catastrophic ignition.

NASA will close and evaluate the following University Leadership Initiative awards.

- Texas A&M University: Reduction of supersonic noise for various atmospheric conditions by changing the aircraft outer mold line.
- University of Tennessee: Improvement of aerodynamic efficiency of slotted natural laminar flow aircraft.
- Arizona State University: Improvement of risk prediction of the National Airspace System with information fusion and prognostics.
- Carnegie Mellon University: Investigation of a scientifically sound basis for qualifying additive manufacturing and demonstrating an ecosystem for efficient large-scale production.
- University of Wisconsin, Madison: Investigation of new methods in which humans can use robotics to improve the efficiency and flexibility of aviation-related manufacturing processes that enhances the safety of human workers.

NASA will deploy a new propulsion simulation calibration and testing capability for aircraft and spacecraft models at Ames Research Center's Unitary Plan Wind Tunnel. This new capability will enable acquisition of next generation aerodynamic test data from aircraft and spacecraft models that integrate with propulsion simulators (e.g., air ejection nozzle or air-powered turbine propulsion simulators).

Hypersonic Capabilities

NASA will experiment with automatically transitioning between a live turbojet engine and a dual mode ram jet simulator in a combined cycle engine system. These experiments will validate the control theory and methods for such transition. To ensure operability while maximizing system performance requires automated control for successful operation of a combined cycle system.

Programs

AIRSPACE OPERATIONS AND SAFETY PROGRAM

AOSP develops and explores fundamental concepts, algorithms, and technologies to increase throughput and efficiency of the NAS safely. The program works in close collaboration with the FAA and the aviation community to establish a vision for future airspace operations and to enable and extend the benefits of NextGen, the Nation's program for modernizing and transforming the NAS to meet evolving user needs. Integrated demonstrations of these advanced technologies will lead to clean air transportation systems and gate-to-gate efficient flight trajectories. The program researches increasingly autonomous aviation systems, including innovation in the management of UAS traffic and other novel aviation vehicles and business models. The program is also pioneering the real-time integration and analysis of data to support system-wide safety assurance, enabling proactive and prognostic aviation safety assurance. The program is addressing the need for improved aerial responses to wildfires by leveraging NASA's UAS traffic management capabilities. The program takes lead responsibility for three of ARMD's Strategic Thrusts:

- Thrust 1: Safe, Efficient Growth in Global Operations;
- Thrust 5: In-Time, System-Wide Safety Assurance; and
- Thrust 6: Assured Autonomy for Aviation Transformation (co-lead).

ADVANCED AIR VEHICLES PROGRAM

AAVP develops the tools, technologies, and concepts that enable new generations of civil aircraft that are safer, more energy-efficient, and have a smaller environmental footprint. The program focuses on enabling major leaps in the safety, efficiency, and environmental performance of subsonic fixed and rotary wing aircraft to meet challenging and growing long-term civil aviation needs; pioneering low-boom supersonic flight to achieve new levels of global mobility; and advancing fundamental hypersonic research while sustaining hypersonic competency for national needs. In collaboration with academia, industry, and other Government agencies (e.g., FAA), AAVP pioneers fundamental research and matures the most promising technologies and concepts for transition to system application by the aviation industry. The program works with the DoD to ensure that NASA and DoD vehicle-focused research is fully coordinated and leveraged. The program takes lead responsibility for three of ARMD's Strategic Thrusts:

- Thrust 2: Innovation in Commercial Supersonic Aircraft;
- Thrust 3: Ultra-Efficient Subsonic Transports; and
- Thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles.

INTEGRATED AVIATION SYSTEMS PROGRAM

IASP focuses on experimental flight research and the spirit of integrated, technological risk-taking that can demonstrate transformative innovation. Therefore, the program complements both AOSP and AAVP by conducting research on the most promising concepts and technologies at an integrated system-level. The program explores, assesses, and demonstrates the benefits of these potential technologies in a relevant environment. The program supports the flight research and demonstration needs across all six ARMD Strategic Thrusts, but it shares lead responsibility with AOSP for the following Strategic Thrust:

- Thrust 6: Assured Autonomy for Aviation Transformation (co-lead).

TRANSFORMATIVE AERONAUTICS CONCEPTS PROGRAM

TACP cultivates multi-disciplinary, revolutionary concepts to enable aviation transformation and harnesses convergence in aeronautics and non-aeronautics technologies to create new opportunities in aviation. The program's goal is to demonstrate initial feasibility of internally and externally originated concepts to support the discovery and initial development of new, transformative solutions for all six ARMD Strategic Thrusts. The program provides flexibility for innovators to explore technology feasibility and provide the knowledge base for transformational aviation concepts through sharply focused activities. The program solicits and encourages revolutionary concepts, creates the environment for researchers to become immersed in new ideas, performs ground and small-scale flight tests, allows failures and learns from them, and drives rapid turnover into new concepts. The program also supports research and development of major advancements in cross-cutting computational tools, methods, and single discipline technologies to advance the research capabilities of all aeronautics programs.

AEROSCIENCES EVALUATION AND TEST CAPABILITIES

The aerosciences ground test research capabilities (e.g., facilities, systems, workforce, and tools) necessary to develop future air and space vehicles require efficient and effective investment, use, and management of NASA's suite of world-class wind tunnels. Efforts in this area preserve and enhance those specific ground test capabilities that are necessary to achieve the missions. Among these assets are subsonic, transonic, supersonic, and hypersonic wind tunnels and propulsion test facilities at the Ames Research Center in Mountain View, CA, the Glenn Research Center in Cleveland, OH, and the Langley Research Center in Hampton, VA. These test facilities and capabilities also serve the needs of non-NASA users. NASA also offers research customers high-quality data that accurately reflect the simulated test environment and the interactions of test articles in those test environments in conjunction with the ground experimentation capabilities. Furthermore, NASA expertise helps ensure safe and successful use of the assets and high-quality of the research outcomes. The project is cross-cutting and supports all ARMD Strategic Thrusts as well as other Agency efforts and those of key industry partners.

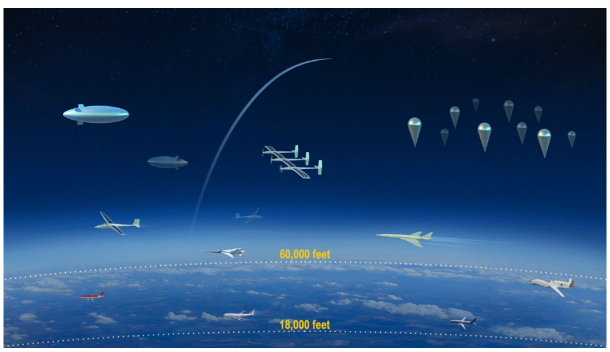
AIRSPACE OPERATIONS AND SAFETY PROGRAM

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**132.0**	**147.4**	**156.2**	**159.0**	**164.2**	**183.6**	**196.8**
Change from FY 2022 Budget Request			**8.8**				
Percent change from FY 2022 Budget Request			**6.0%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



Technologies proven through NASA's Unmanned Aircraft System Traffic Management (UTM) research are being examined as possible solutions for keeping vehicles above 60,000 feet safely separated.

The U.S. air transportation system is one of the most efficient and safest systems in the world. NASA has substantially contributed to the Federal Aviation Administration (FAA)-led NextGen modernization effort that will meet growing air traffic demand by enabling efficient passage through the increasingly crowded skies. However, there are additional opportunities for reducing fuel burn, aircraft emissions, and environmental impacts through increased operational efficiency.

Moreover, the integration of new vehicles and types of missions into the National Airspace System (NAS) will require advanced concepts and capabilities to accommodate the volume, diversity, and complexity of operations efficiently and safely in a digitally integrated environment.

Advanced automation technologies are foundational for safe and efficient operations in this complex and dynamic environment. This automation must work in an integrated fashion across multiple domains and stakeholders and in harmony with human operators. NASA is working with FAA to develop a long-term vision for the future NAS and looking to ensure that the system will accommodate these diverse and increasingly complex operations in a safe and affordable manner for service providers, vehicle operators, passengers, and cargo. In the coming years, the sustained, integrated efforts of the FAA and its many stakeholders will systematically transform the systems and processes of today's NAS to accommodate these new operations. NASA will play a critical role in this transformation through its research and development of autonomous technologies for aircraft as well as tools and technologies for managing the airspace to support increasingly diverse operations.

The Airspace Operations and Safety Program (AOSP) performs research and technology to develop transformational air traffic management and operational safety concepts. These technologies benefit the public by increasing capacity, decreasing fuel consumption, and reducing the total cost of air transportation. Increased operational efficiency at the vehicle-, fleet-, and system-levels reduces fuel burn

AIRSPACE OPERATIONS AND SAFETY PROGRAM

and emissions; and integrated ground and flight-based technologies will enable trajectory optimization through every phase of flight. With the FAA, industry, and academic partners, AOSP conceives, develops, and demonstrates technologies to improve the safety of current and future aircraft systems that will operate in the NAS. Furthermore, the program develops advanced technologies for a service oriented and federated NAS architecture to enable seamless integration of emergent vehicles (e.g., Unmanned Aircraft Systems [UAS] and Advanced Air Mobility [AAM] vehicles) with present-day aircraft. These new vehicle operations can transform the way we move people and cargo and will enable a variety of public good missions including medical missions and emergency response operations. AOSP also works with other ARMD programs to define safe NAS operational requirements for the next generation of vehicles, mature new transformative seedling concepts, and demonstrate integrated systems. AOSP directly supports three of the ARMD Strategic Thrusts:

- Thrust 1: Safe, Efficient Growth in Global Operations;
- Thrust 5: In-Time System-Wide Safety Assurance; and
- Thrust 6: Assured Autonomy for Aviation Transformation.

EXPLANATION OF MAJOR CHANGES IN FY 2023

NASA will initiate a new project, Advanced Capabilities for Emergency Response Operations (ACERO), aimed at improving aerial responses to wildfires. The project will leverage NASA developed UAS traffic management capabilities and begin to develop an interagency concept of operations with other Federal, State, and local agencies.

NASA will transfer the Advanced Air Mobility (AAM) project from the Integrated Aviation Systems Program to the Airspace Operations and Safety Program. The AAM project relies on air traffic management capabilities developed by AOSP. Therefore, this realignment will maximize the synergies between the AAM project and AOSP's current projects, Air Traffic Management eXploration (ATM-X), System Wide Safety, and Advanced Capabilities for Emergency Response Operations.

ACHIEVEMENTS IN FY 2021

At the end of each achievement identified in this document, there is a parenthetical to link it to the related Strategic Research Thrust and Program Element.

- NASA conducted the final Airspace Technology Demonstration (ATD) demonstration at the Dallas/Fort Worth and Dallas Love Field airports. The demonstration involved American Airlines and Envoy Air facilities at Dallas/Fort Worth and Southwest Airlines facilities at Dallas Love Field. This was a high-fidelity demonstration of all Integrated Arrival/Departure/Surface system capabilities. This demonstration validated the use of strategic surface metering during periods of significant demand/capacity imbalance to reduce fuel burn and emissions for more sustainable aviation operations. Benefits totals from Phase 3 of the ATD-2 field demonstrations in Dallas Fort Worth from November 2020 to September 2021 resulted in savings of 50,857 pounds of fuel, 156,641 pounds of CO2 emissions, reduced North Texas Research Station System-wide delay by 26 hours and saved operators an estimated $18,267 in flight crew costs, and passengers $79,642 in value of time. (Thrust 1/ Airspace Technology Demonstration [ATD])

AIRSPACE OPERATIONS AND SAFETY PROGRAM

- NASA formally closed out the ATD project, final deliverables, and research documentation was sent to the FAA Research Transition Team. With this project close-out, NASA's ATD-1, ATD-2, and ATD-3 contributions to the FAA's NextGen effort are complete. NASA technologies deployed as part of FAA's NextGen will help airlines realize significant operational benefits and passengers save valuable time. (Thrust 1/ATD)
- NASA launched an interactive web portal for gathering and assessing community feedback to co-develop the Sky For All vision with stakeholders. The first version gathered contributions from approximately 70 NASA subject matter experts, while the second version gathered input from a broad Aeronautics Research Mission Directorate audience. (Thrust 1/ATM-X)
- NASA delivered airspace management capabilities to enable AAM operations and airspace integration to support the AAM National Campaign demonstrations. This airspace and traffic management capability for AAM vehicles is critical to the demonstrations. (Thrusts 1 and 6/ATM-X)
- NASA successfully completed the National Campaign (NC) Development Testing with an industry partner to demonstrate the maturity of key systems and infrastructure that will be employed for the National Campaign series beginning with NC 1 in FY 2022. (Thrusts 1 and 6/AAM)
- NASA developed techniques that process relevant vehicle and operational environment information to monitor and make predictions about system safety in order to evaluate potential courses of action. This research is critical to the development of an advanced in-time system-wide safety assurance system, that would enable automated monitoring, assessment, and mitigation of risks. (Thrust 5/System Wide Safety [SWS])
- NASA conducted an UTM Technical Interchange Meeting and completed the final closeout of the UTM project. NASA and the FAA issued a joint final report on the UTM Pilot Program. (Thrust 6/UTM)
- NASA evaluated a tool that actively monitors machine learning-enabled components while in operation to constrain the overall behavior of an autonomous system. This capability will enable the FAA to develop requirements for certification of autonomous systems. (Thrust 6/SWS)

WORK IN PROGRESS IN FY 2022

- NASA will conduct a study to assess separation impacts associated with changes to roles and responsibilities, and allocation of airspace functions necessary to integrate large autonomous aircraft in low complexity terminal airspace shared with conventional aircraft. (Thrust 1/ATM-X)
- NASA will work with industry partners to demonstrate a trajectory management service that enables flight operators to identify efficient departure routes and improve the environmental sustainability of air transportation. (Thrust 1/ATM-X)
- NASA will engage with industry to develop and evaluate novel air traffic management capabilities for AAM vehicles in flight. These capabilities will undergo rigorous validation in a controlled environment before transitioning to field demonstrations. (Thrust 6/ATM-X)
- In collaboration with the FAA, NASA will use an interactive web-based portal to co-develop a vision that describes characteristics of NAS operations in 2045 with a broad set of stakeholders. (Thrust 1/ATM-X)

AIRSPACE OPERATIONS AND SAFETY PROGRAM

- NASA will continue to focus on investigating barriers of entry into new emerging markets in aviation. AOSP will closely coordinate with related NASA research on both airspace operations and vehicle technologies to help prioritize and deliver on the key enabling technical challenges that are most appropriate for NASA to work. Based on National Campaign Development Testing conducted in FY 2021, NASA will share lessons learned and identified requirements and standards gaps with the FAA and industry. National Campaign will conduct a flight series with industry partners to exercise ecosystem-wide system-level safety and integration scenarios and scalable system concepts. (Thrust 1 and 6/AAM)
- NASA will deliver draft evidence and recommendations to industry standards committees and safety and regulatory partners on the use of run-time monitoring for automated components and the robustness of remote operators as a backup in case of automation failure. (Thrust 6/SWS)
- NASA will evaluate the potential benefits of including non-traditional data sources, such as third-party data and/or human performance data, together with traditional aviation safety data to evaluate overall risk. (Thrust 5/SWS)

KEY ACHIEVEMENTS PLANNED FOR FY 2023

- NASA will form a foundation for the development and use of advanced artificial intelligence (AI) and machine learning airspace services. This will be done by collaboratively demonstrating a prototype cloud-based digital information platform that improves the ability for operators to access and share airspace data. (Thrust 1/ATM-X)
- NASA will initiate a new project, Advanced Capabilities for Emergency Response Operations (ACERO), aimed at improving aerial responses to wildfires. The project will leverage NASA developed UAS traffic management capabilities and begin to develop an interagency concept of operations with other Federal, State, and local agencies. (Thrust 1,5, and 6/ACERO)
- NASA will conduct Integration of Automated Systems (IAS) Flight Testing. IAS flights are focused on testing new technologies related to AAM. NASA will share lessons learned and identified requirements and standards gaps with the FAA and industry. (Thrusts 1 and 6/AAM)
- NASA will analyze aircraft and ground operations data from partners, flight tests, and simulations. The analysis will show where NASA developed monitoring, assessment, and mitigation techniques can be used in future aviation operations. (Thrust 5/SWS)
- NASA will demonstrate algorithms to analyze safety standards for systems that rely on untrusted components, used for increasingly autonomous aviation surface and drone flight operations. (Thrust 6/SWS)
- NASA will advance the capability of airspace services necessary to enable AAM operations by working collaboratively with industry partners to identify, implement, and test community-based rules for pre-departure scheduling and strategic deconfliction services. (Thrust 6/ATM-X)

AIRSPACE OPERATIONS AND SAFETY PROGRAM

Program Elements

AIR TRAFFIC MANAGEMENT – EXPLORATION (ATM-X)

The ATM-X project will transform the air traffic management system to accommodate the growing demand of new entrants with new mission requirements while also allowing established, large commercial aircraft operators to fly more user-preferred routes with improved predictability. The project is exploring challenging use cases in an open airspace management system architecture to establish key performance parameters and prioritize technical challenges. An example exercise is the definition of requirements for high-density vertical lift vehicle operations for AAM. ATM-X will provide an early demonstration of emerging market operations by simulating higher levels of industry-provided services to validate the potential for more rapid modernization by incorporating innovations at "industry" speeds. ATM-X is developing airspace requirements for managing AAM aircraft for ARMD's AAM National Campaign.

The ATM-X project is focused on demonstrating, through an open architecture approach, that integration of air traffic technologies, system-wide data use, advances in human-machine teaming, and increasingly autonomous decision-making will provide comprehensive situational awareness, coordinated decision-making, and improved disruption management. This demonstration will incorporate advanced, machine-learning, and artificial intelligence capabilities for air traffic management and contingency management that will enable flexible, user-preferred, predictable, and robust airspace operations. ATM-X is also exploring advanced trajectory management services and advanced flight deck capabilities to enable efficient, environmentally sustainable operations. The project will validate and transfer key concepts and technologies to FAA and industry stakeholders to enable transformation of the NAS.

SYSTEM-WIDE SAFETY (SWS)

The SWS project develops tools, methods, and technologies to enable capabilities envisioned by ARMD's Strategic Thrust 5 (In-Time System-Wide Safety Assurance). The SWS project performs research to explore and understand the impact on safety of the complexity introduced by technology advances, particularly those aimed at improving the efficiency of flight, broadening access to airspace, and expanding the types of service provided by air vehicles. The project also develops and demonstrates innovative solutions that enable the aviation transformation envisioned by ARMD through proactive and proactive mitigation of risks in accordance with target levels of safety. The following are drivers of increased system safety awareness:

- Increased access to relevant data;
- Integrated analysis capabilities;
- Improved real-time detection and alerting of hazards at the domain-level;
- Decision support; and
- In some cases, automated mitigation strategies.

AIRSPACE OPERATIONS AND SAFETY PROGRAM

The SWS project also addresses the need, identified in Strategic Thrusts 1 and 6, for safety-related advances in methods used for the verification and validation of machine learning-enabled components and advanced, increasingly autonomous systems.

ADVANCED CAPABILITIES FOR EMERGENCY RESPONSE OPERATIONS (ACERO)

The ACERO project leverages NASA-developed tools and technologies to improve aerial response for wildland fire fighting and advances NASA's efforts in Strategic Thrusts 1, 5, and 6. The ACERO project works with other Government agencies and regional fire response organizations to develop and demonstrate capabilities for the coordination of aerial assets and real-time data exchange to increase the duration and density of aerial firefighting operations. The project will initially focus on establishing a common, multi-agency concept of operations to enable more streamlined coordination of aerial wildfire response efforts. The project will demonstrate a common interoperable platform for situational awareness of all aerial assets and data. Longer term objectives include the development of advanced aircraft and airspace management capabilities to enable diverse simultaneous crewed and uncrewed operations for persistent (up to 24 hours per day) observation and suppression operations.

ADVANCED AIR MOBILITY (AAM)

The AAM project focuses on helping to safely develop the emerging market in urban, suburban, rural, and regional environments. This project closely coordinates with ARMD's other programs on both airspace operations and vehicle technologies to help prioritize and deliver on the key enabling technical challenges that are most appropriate for NASA to work on. The AAM project will conduct focused research in key areas, such as autonomy required to achieve NASA's vision for advanced air mobility. One of the primary functions of the project is to execute a series of AAM National Campaign demonstrations which will promote public confidence in AAM safety, facilitate aviation community-wide learning and help identify the focus of future research. AAM works closely with other Government and commercial entities to achieve this objective.

Program Schedule

Date	Significant Event
Sep 2022	SWS – Evaluate the potential benefits of including non-traditional data sources, together with traditional aviation safety data to evaluate overall risk. ATM-X – Collaborate with industry to develop and evaluate novel air traffic management capabilities for AAM vehicles in flight. These capabilities will undergo rigorous validation in a controlled environment before transitioning to field demonstrations. ATM-X –With industry partners, demonstrate a trajectory management service to enable flight operators to identify efficient departure routes and improve the environmental sustainability of operations. AAM - Complete AAM National Campaign 1 (NC 1)
Jul 2023	AAM – End of Scalable Autonomous Operations UAS Flight Test

AIRSPACE OPERATIONS AND SAFETY PROGRAM

Date	Significant Event
Sep 2023	ATM-X – Demonstrate the use of advanced AI and machine learning airspace services by collaboratively demonstrating a prototype cloud-based digital information platform that improves the ability for operators to access and share airspace data. ATM-X – Advance the capability of airspace services necessary to enable AAM operations by working collaboratively with industry partners to identify, implement, and test community-based rules for pre-departure scheduling and strategic deconfliction services. SWS – Analyze aircraft and ground operations data from partners, flight tests, and simulations and make recommendations for applying NASA's developed safety assessment techniques to future aviation operations. ACERO – Demonstrate develop an interagency concept of operations with other Federal, State, and local agencies for wildfire response operations.
Oct 2023	AAM – Complete Integration of Automated Systems - 1 Flight Test
Aug 2024	AAM – End of Vertiport Automation UAS Flight Test
Aug 2025	AAM – Complete Integration of Automated Systems - 2 Flight Test

Program Management & Commitments

Program Element	Provider
Air Traffic Management - Exploration (ATM-X)	Provider(s): Ames Research Center (ARC), Langley Research Center (LaRC), Glenn Research Center (GRC) Lead Center: ARC Performing Center(s): ARC, LaRC, GRC, AFRC Cost Share Partner(s): FAA, German Aerospace Center (DLR), JAXA, American Airlines, Southwest, Dallas Fort Worth Airport (DFW), AURA, ANRA Technologies, ARINC Inc., Avision Inc., Metron Aviation Inc., OneSky Systems Inc., SkyGrid, Unmanned Experts Inc.
System-Wide Safety (SWS)	Provider(s): ARC, LaRC, GRC Lead Center: LaRC Performing Center(s): ARC, LaRC, GRC, AFRC Cost Share Partner(s): FAA, DoD Air Force Research Laboratory, Defense Advanced Research Projects Agency, MITRE, Boeing Research & Technology, GE Global Research, American Airlines, Delta Airlines, Swiss International Airlines, Commercial Aviation Safety Team, Drone Safety Team, Association for Unmanned Vehicle Systems International, RTCA, Society of Automotive Engineers, Flight Safety Foundation, Texas A&M Lone Star UAS Center of Excellence, Federal Bureau of Investigation
Advanced Capabilities for Emergency Response Operations (ACERO)	Provider(s): TBD Lead Center: TBD Performing Center(s): TBD Cost Share Partner(s): TBD

AIRSPACE OPERATIONS AND SAFETY PROGRAM

Program Element	Provider
Advanced Air Mobility (AAM)	Provider(s): ARC, AFRC, GRC, LaRC Lead Center: HQ Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): N/A

Acquisition Strategy

AOSP research and technology spans from foundational research to integrated system capabilities. This broad spectrum necessitates the use of a wide array of acquisition tools relevant to the appropriate work awarded externally through full and open competition. For all procurement actions, NASA strongly encourages teaming among large companies, small businesses, and universities.

MAJOR CONTRACTS/AWARDS

AOSP awards multiple smaller contracts, which are generally less than $5 million and widely distributed across academia and industry.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Expert Review	Oct 2021	The 12-month review is a formal independent peer review. Experts from other Government agencies report on their assessment of technical and programmatic risk and/or program weaknesses.	Determined that the projects made satisfactory progress in meeting technical challenges and all annual performance indicators.	Oct 2022

ADVANCED AIR VEHICLES PROGRAM

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**211.4**	**243.7**	**253.2**	**269.5**	**287.2**	**270.5**	**235.9**
Change from FY 2022 Budget Request			**9.5**				
Percent change from FY 2022 Budget Request			**3.9%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Pictured above is a scale model of the Transonic Truss-Braced Wing concept during testing in the Langley Research Center 14- by 22-Foot Wind Tunnel. Wind-tunnel testing with industry partners validates environmental benefits.

The Advanced Air Vehicles Program (AAVP) develops knowledge, technologies, tools, and innovative concepts to enable safe new aircraft that will fly faster, cleaner, and quieter and use fuel far more efficiently than in the past. All large modern United States aircraft incorporate NASA research and technology. The type of research performed by AAVP will prime the technology pipeline, enabling continued United States leadership, competitiveness, and high-quality jobs in the future. These advanced, integrated technologies and capabilities improve vehicle performance by reducing fuel consumption, noise, and emissions without adversely affecting vehicle safety. Fuel efficiency and environmental factors will play an increasingly significant role as the aviation market grows in capacity and as airlines, manufacturers, and regulators commit to new environmental targets and explore new markets.

AAVP develops a broad range of technologies that help ensure continued United States industrial leadership that will benefit both the economy and the environment. Specifically, with respect to subsonic transport aircraft and as part of NASA's leadership of the Sustainable Flight National Partnership, AAVP accelerates development of key subsonic technologies to ensure they will be ready by the mid- to late-2020s to transition into United States industry's next generation single-aisle transport aircraft. Across the program, NASA will continue to engage partners from industry, academia, and other Government agencies to maintain a broad perspective on technology solutions to these challenges, to pursue mutually beneficial collaborations, and to leverage opportunities for effective technology transition. AAVP directly supports three of the Aeronautics Research Mission Directorate (ARMD) Strategic Thrusts:

- Thrust 2: Innovation in Commercial Supersonic Aircraft;
- Thrust 3: Ultra-Efficient Subsonic Transports; and
- Thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles.

ADVANCED AIR VEHICLES PROGRAM

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

ACHIEVEMENTS IN FY 2021

At the end of each achievement identified in this document, there is a parenthetical to link it to the related Strategic Research Thrust and Program Element.

- NASA initiated efforts focused on Advanced Air Mobility (AAM) vehicle ride quality, exploring the competing characteristics of vehicle handling qualities and passenger ride quality. NASA conducted a flight simulation of a NASA multirotor reference vehicle to explore vehicle handling qualities and how vehicle motion can impact passenger ride comfort. NASA also did a preliminary study of the effect of vehicle motion on passengers. (Thrust 4/Revolutionary Vertical Lift Technology [RVLT])
- NASA conducted a series of public workshops co-sponsored with the Federal Aviation Administration (FAA) to examine aspects of crashworthiness of AAM vertical-lift vehicles. NASA's new area of focus emphasizes occupant protection to address fundamental safety questions for AAM vehicles and provide information to standards organizations. (Thrust 4/RVLT)
- NASA acquired noise measurements of an AAM vehicle during flight tests. The noise data will establish baseline acoustic levels for AAM vehicles and give insight into the noise characteristics of this new type of aircraft. (Thrust 4/RVLT)
- NASA met with standard-setting organizations to provide a broad range of technically-sound data for use in setting industry standards of practice, including areas of aircraft noise measurement and modeling, high voltage power quality, and aircraft icing. (Thrust 4/RVLT)
- NASA conducted wind tunnel tests on a 10 percent scale aircraft research model that included high-lift features and "common" attributes that enable testing at multiple facilities across the United States. The tests helped establish the feasibility of quiet high-lift technology concepts. These technology concepts consist of filling the gaps between aircraft wing leading- and trailing-edge flaps and slats, which produce a large fraction of aircraft noise on approach. This research helped advance wing designs integral to future quiet aircraft. This effort is part of a broader noise reduction technology development effort which also included turbofan engine acoustic liners. These noise reduction technologies targeted noise levels approximately 25 percent lower than existing technology. These technologies will benefit the aviation industry by helping to ensure quiet operation of aircraft near airports. (Thrust 3/Advanced Air Transport Technology [AATT])
- NASA completed testing and analysis of components for advanced, fuel-efficient turbofan engines developed in partnership with industry, including advanced compressor components and high-temperature turbine disks and seals. These technologies were critical for advancing small-core turbofan engines with higher engine bypass and pressure ratios to improve fuel efficiency. (Thrust 3/AATT)
- NASA awarded six NASA Research Announcement (NRA) contracts to United States aircraft engine manufacturers to develop small core technologies that will advance the efficiency of turbofan engines. These efforts form the foundation of the new Hybrid Thermally Efficient Core (HyTEC) project that will culminate in an advanced core demonstration in the 2026 timeframe. Once

demonstrated, these technologies will enable advanced, high efficiency engines for future single-aisle aircraft. (Thrust 3/HyTEC)

- NASA established cooperative agreements with the members of the Advanced Composites Consortium (ACC) to aid in the formulation of the Hi-Rate Composite Aircraft Manufacturing (HiCAM) project. NASA and ACC members collaborated to develop system requirements and baseline definitions, conduct assessments of high-rate manufacturing technologies, define technology gaps, and prioritize content for future development under the HiCAM project. By collaborating with technical experts and stakeholders representing the composites manufacturing supply chain, NASA developed a team vision, ensured relevance to industry needs, and increased the likelihood of technologies transitioning into future U.S. aircraft programs. (Thrust 3/Hi-Rate Composite Aircraft Manufacturing [HiCAM])
- NASA planned a sonic boom wind tunnel test using a 1.6 percent scale model of the X-59 vehicle. The wind tunnel test supports development and validation of computer-based simulation tools and provides pre-flight validation data for the Low Boom Flight Demonstrator. (Thrust 2/Commercial Supersonic Technology [CST])
- NASA continued preparing for the X-59 flight validation tests by awarding a contract for the ground-level noise recording systems and by establishing a support contractor team of subject matter experts to aid in the planning and testing with the X-59. NASA continued to engage the international community on standards and certification procedures for en route noise. (Thrust 2/CST)
- NASA applied calibrated mathematical models to predict hypersonic flight test performance including a quantified level of uncertainty in the prediction. NASA developed an approach to optimize a design, with quantified uncertainties, and then applied this approach to a Turbine-Based Combined Cycle (TBCC) propulsion component. These uncertainty quantification (UQ) methods will be available for use on future design and analysis efforts. (Hypersonic Technology [HT])
- NASA implemented its calibrated UQ methods, along with Computational Fluid Dynamics (CFD) capabilities, to design a TBCC propulsion component. Fabrication and ground testing of the component will occur in the 4-foot by 4-foot Unitary Plan Wind Tunnel. The pre-test CFD predictions with UQ estimates, when compared to the experimental data with measurement uncertainties, will determine how accurately NASA's computational tools make predictions for this TBCC propulsion component. (HT)

WORK IN PROGRESS IN FY 2022

- NASA will conduct multiple wind tunnel experiments of different single-rotor and multi-rotor vertical lift vehicle configurations, providing data to validate several computer-based design methods for NASA and the AAM industry. (Thrust 4/RVLT)
- NASA will initiate system testing for components of electric propulsion systems for AAM, which will use a 150-kilowatt (kW) electromechanical powertrain test rig and several motor emulators to simulate multiple motor loads. As part of an effort to both understand and predict component failure, NASA will gather data to validate computer-based predictive models and will explore potential failure modes and mitigation strategies. These research efforts provide vital data to regulatory agencies, such as the FAA, for developing means of compliance for safety standards. (Thrust 4/RVLT)

ADVANCED AIR VEHICLES PROGRAM

- NASA will demonstrate improved computer-based tools for predicting and evaluating the noise and performance of AAM vehicle configurations. These efforts will benefit the AAM community by providing design tools and guidelines that will increase the likelihood that their new aircraft designs will meet noise goals before the development and construction of a full-scale vehicle. (Thrust 4/RVLT)
- NASA will develop a method to evaluate the noise impact of a fleet of AAM vehicles. The method for assessing fleet operations is essential for Government and industry use in minimizing the overall noise impacts of AAM operations. (Thrust 4/RVLT)
- To help enable future large-scale electrified aircraft propulsion systems, NASA will test megawatt (MW)-scale aircraft electrical powertrains and flight-weight, flight-like inverters under flight altitude conditions. This testing is done at the NASA Electric Aircraft Testbed (NEAT) facility at simulated flight altitude (30,000 feet) conditions and will be the first MW-class electrified powertrain testing at this facility. The test will establish the practicality of employing these types of components in future aircraft systems while ensuring safe and efficient operations under flight conditions. Additionally, in engagement with industry, NASA will demonstrate feasibility of fault management devices for MW- and kilovolt-class electrified aircraft powertrains. (Thrust 3/AATT)
- NASA, in collaboration with industry, will conduct aerodynamic buffet testing of a Transonic Truss-Braced Wing (TTBW) model to better understand the aerodynamics of this concept. This testing will advance the technology readiness level of the TTBW for potential flight testing and future market opportunities. (Thrust 3/AATT)
- NASA will award additional technology development contracts for small core combustor designs that provide reliable ignition and lean blowout performance when using a high blend (greater than 80 percent) sustainable aviation fuel (SAF). These contract(s) will demonstrate the effectiveness and efficiency of using high blend SAF in turbofan engine combustors entering service in the 2030s and assess the SAF impact on the propulsion system performance. (Thrust 3/HyTEC)
- In collaboration with industry, NASA will complete analysis of durability testing of ceramic matrix composite turbine blades. This work will ensure that high-temperature capable turbine blades meet durability requirements for use in future commercial turbofan engines. (Thrust 3/HyTEC)
- NASA will complete formulation of the HiCAM project. NASA will set project requirements and complete screening of manufacturing technologies based upon their potential impact on manufacturing rate, cost, and factory size. (Thrust 3/HiCAM)
- NASA will select an initial set of technologies to enable high-rate composite manufacturing and conduct small scale experimental evaluations in preparation to down-select technologies for further development at the larger-scale structural panel level. (Thrust 3/HiCAM)
- NASA will conduct sonic boom wind tunnel testing using a 1.6 percent scale model of the Low Boom Flight Demonstrator (X-59). The wind tunnel tests will provide additional experimental data for the X-59 to use in conjunction with the analytical and flight data. The data will support development and validation of computer-based prediction tools which are essential for predicting noise values measured during future flights. Additionally, the noise predictions will help inform researchers how to best measure X-59 flight noise. (Thrust 2/CST)
- NASA will conduct flight experiments using test aircraft at the Armstrong Flight Research Center (AFRC) to evaluate the initial version of the ground-level noise recording systems. Evaluating these

ground recording systems will ensure that they are ready to accurately record ground-level noise from X-59 flights. (Thrust 2/CST)

- NASA will develop survey plans for community response testing and plans for communications and outreach during X-59 future community overflight testing. These community surveys will collect information on responses to the X-59's low boom flights, which NASA will provide to United States and international standards bodies. (Thrust 2/CST)
- NASA will conduct acoustic flight tests that will help improve the ability to predict jet noise near airports. This data will help regulators set appropriate limits on landing and takeoff noise for new commercial supersonic aircraft. (Thrust 2/CST)
- NASA will experiment with automatic transitions between a real-time turbojet engine simulator and a dual mode ram jet simulator in a combined cycle engine system. These experiments will establish the control theory and methods for such transition. To ensure operability while maximizing system performance requires automated control for successful operation of a combined cycle system. (HT)
- NASA will develop cutting-edge methods to design hypersonic aircraft, while accounting for uncertainties in the design predictions, using validated models and flight performance data. Additionally, NASA will investigate high temperature, durable materials to advance state-of-the-art material systems and improve performance. These capabilities will enable the hypersonic, airbreathing research community to make informed decisions in their designs. (HT)
- NASA will conduct surface roughness experiments related to two sounding rocket flights by the Air Force Office of Scientific Research. Using ground test data and flight data as appropriate, NASA will study hypersonic boundary layer transition on complex, three-dimensional geometries, which will reduce vehicle-level uncertainty and maximize performance. (HT)

KEY ACHIEVEMENTS PLANNED FOR FY 2023

- NASA will complete work on a validated set of computer-based analysis tools, including thermal modeling, to calculate the reliability of an electric motor design for AAM applications. NASA will provide the methodology to the industry community through publications so that the capabilities can be used. (Thrust 4/RVLT)
- By working with the relevant SAE Standards Committee, NASA will contribute to defining technical standards for AAM power quality that will improve the reliability and safety of AAM vehicles. (Thrust 4/RVLT)
- NASA will complete an electric motor noise model and incorporate it into publicly available acoustic prediction tools for use in improving the ability to predict the full spectrum of noise for AAM vehicles. (Thrust 4/RVLT)
- In collaboration with industry, NASA will demonstrate a hybrid-electric powertrain for transport-class aircraft that has a total power of at least three times the nominal 260 kW state-of-the-art. This demonstration will include the flight-weight and flight-like components required to bring the technology to flight. Further, the system will also meet safety requirements for fault management, redundancy, and power quality needed for use on commercial transports. In taking this approach, future transports will be able to use hybrid propulsion technologies for aircraft efficiency benefits. (Thrust 3/AATT)

- NASA will partner with the FAA to conduct a series of flights to study how atmospheres that are high in aerosols affect ice crystals at altitude. Reducing the uncertainty of this icing phenomenon will improve the accuracy of NASA's icing prediction tools. Reduced uncertainty will enable industry to better predict dangerous icing conditions and avoid encountering them or potentially develop engine designs that are safer under such conditions. (Thrust 3/AATT)
- NASA will award contracts for the demonstration of integrated core engine technologies in an environment that simulates flight conditions. This demonstration will show sufficient technical maturity that the demonstrated technologies may be considered for inclusion on next-generation aircraft engines. (Thrust 3/HyTEC)
- NASA will complete small core technology development tests, demonstrating a suite of compressor, turbine, and material technologies tested in laboratory environments. These technologies can then be incorporated into future small core demonstrations for the next single-aisle aircraft. (Thrust 3/HyTEC)
- NASA will down-select technologies to enable high-rate composite manufacturing and initiate development at the larger-scale structural panel level. Demonstrations at the structural panel level will inform future selections for demonstration on full-scale aircraft components. (Thrust 3/HiCAM)
- NASA will award cooperative agreements for the preliminary design of full-scale aircraft components for future tests that will demonstrate structural performance and high-rate manufacturing technology. (Thrust 3/HiCAM)
- NASA will update best practices for predicting ground acoustic volume of the Low-Boom Flight Demonstrator with improved computational prediction tools. These tools will then be applied during the X-59 validation flights to compare predictions to measurements and further improve the computational prediction tools. (Thrust 2/CST)
- NASA will gather ground level noise data for the X-59 for use in verifying the acoustic characteristics and for validation of computational tools. (Thrust 2/CST)
- NASA will prepare test plans, develop procedures, and procure equipment in preparation for overflight tests with the X-59 aircraft over large, non-experienced communities located in the United States. (Thrust 2/CST)
- NASA will experiment with automatic transitions between a live turbojet engine and a dual mode ram jet simulator in a combined cycle engine system. These experiments will validate the control theory and methods for such transition. To ensure operability while maximizing system performance requires automated control for successful operation of a combined cycle system. (HT)

Program Elements

REVOLUTIONARY VERTICAL LIFT TECHNOLOGY (RVLT)

The RVLT project develops, demonstrates, and validates tools, technologies, and flight operations methods that reduce vertical take-off and landing (VTOL) aircraft noise and improve safety, enabling expanded use of VTOL aircraft in an integrated airspace environment. The unique ability of vertical lift vehicles to hover has significant applications in the civil market for human and cargo transportation and delivery systems as evidenced by the emerging urban air mobility (UAM) industry within the broader advanced air mobility (AAM) industry. Additionally, advanced vertical lift technologies and capabilities are directly relevant to vehicles for inspection and surveillance missions, oil and gas exploration, disaster relief, and many more critical operations. RVLT research advances technologies that will increase safety and reduce noise and annoyance to overcome significant barriers for the emergence of a new UAM and AAM market. To accomplish this research, NASA uses advanced computer-based, multi-fidelity prediction methods, unique NASA facilities, and state-of-the-art experimental techniques. RVLT considers current and future vertical lift vehicles of many classes and sizes, focusing on configurations that are viable as inter-city and intra-city transportation. The RVLT project primarily supports ARMD Strategic Thrust 4 and the Advanced Air Mobility Mission.

ADVANCED AIR TRANSPORT TECHNOLOGY (AATT)

The AATT project seeks to enable revolutionary advancements in future aircraft performance. As part of the NASA-led Sustainable Flight National Partnership, research explores solutions to advance knowledge, technologies, and concepts, enabling major steps in energy efficiency and environmental compatibility and resulting in reductions to fuel burn, harmful emissions, and noise around airports. The research also benefits United States industrial competitiveness in the subsonic transport aircraft market, as well as potentially opening new markets for United States entrants in the regional jet and smaller size classes. The knowledge gained from this research in the form of experiments, data, system studies, and analyses is critical for conceiving and designing more efficient and quieter aircraft. Advanced air transport research directly supports ARMD Strategic Thrust 3 and focuses on developing advanced technologies and tools for future generations of commercial transport – including the emerging area of electrified aircraft propulsion and the supporting engine core research needed to develop new engines that will ultimately power the new vehicles. Although this project focuses on the long-term technology timeframe, it also contributes to both near-term and mid-term development by demonstrating interim technology advancements.

HYBRID THERMALLY EFFICIENT CORE (HYTEC)

The HyTEC project will develop small core turbofan engine technologies aimed at achieving a 5-10 percent fuel burn reduction compared to 2020 best-in-class turbofan engines and up to 20 percent power extraction at altitude, culminating in an advanced core demonstration in the 2026 timeframe. As part of this effort, HyTEC will advance design capabilities for small core combustors for effective and efficient operability on high blend (80-100 percent) sustainable aviation fuels. Within the Sustainable Flight National Partnership, NASA will collaborate with industry in a cost-sharing arrangement on key technologies and will accelerate these key technologies to strengthen the United States industry position on small core-enabling technology and integrated systems for a future single aisle aircraft. HyTEC primarily supports ARMD Strategic Thrust 3.

HIGH-RATE COMPOSITE AIRCRAFT MANUFACTURING (HICAM)

The HiCAM project will demonstrate manufacturing approaches and associated technologies that enable large, composite primary airframe structure production rates four to six times faster than 2020 best-in-class production rates without increasing component cost or weight. The project focus will be airframe structural components for single-aisle transport aircraft expected to enter service in the early to mid-2030s. HiCAM will develop model-based engineering tools to rapidly mature, optimize, and transition high-rate composite manufacturing and assembly methods. NASA will team with partners to share expertise, facilities, and resources to accelerate technology maturation efforts. As part of the Sustainable Flight National Partnership, the HiCAM project technologies will enable advanced vehicle concepts that require composite structures and will introduce manufacturing considerations into future vehicle designs. HiCAM primarily supports ARMD Strategic Thrust 3. However, the findings and techniques developed will generally advance manufacturing technology applicable to a variety of composite structures, including aircraft engine applications, urban air mobility vehicles, and space launch vehicle applications. The findings and techniques may also contribute to future in-space construction and assembly of composite structures.

COMMERCIAL SUPERSONIC TECHNOLOGY (CST)

Supersonic vehicle research includes tools, technologies, and knowledge that will help eliminate today's technical barriers to practical commercial supersonic flight. These barriers include sonic boom noise, supersonic aircraft fuel efficiency, airport community noise, high-altitude emissions, vehicle aeroservoelastic design, supersonic operations, and the ability to design vehicles in an integrated, multidisciplinary manner. The CST project directly supports ARMD Strategic Thrust 2: Innovation in Commercial Supersonic Flight. CST will leverage the X-59 Low-Boom Flight Demonstrator to gather data on the human responses to low-level sonic booms. This human community response data will inform national and international regulatory organizations' efforts to define certification standards that commercial aircraft manufacturers can follow to create new supersonic aircraft markets. In preparation for the use of the X-59 vehicle, CST research will establish the necessary approaches and techniques for objectively measuring the level of supersonic overflight noise acceptable to communities living near future commercial supersonic flight paths. These approaches, techniques, and resulting data will be the foundation for establishing the sonic boom acoustic limits as part of the international certification standards.

HYPERSONIC TECHNOLOGY (HT)

NASA focuses on fundamental research that explores key challenges in hypersonic flight and maintains unique, specialized facilities and experts. The HT project focuses on hypersonic propulsion systems, reusable vehicle technologies, high-temperature materials, and systems analysis. NASA applies its expertise to support and evaluate the potential for future commercial hypersonic markets. In addition, this project coordinates closely with the Department of Defense (DoD), so NASA can leverage DoD investment in ground and flight activities to develop and validate advanced physics-based computational models. At the same time, DoD benefits from NASA expertise, analyses, testing capabilities, and computational models. NASA supports the United States industry's emerging interest in commercial hypersonic vehicles, while also supporting DoD needs.

Program Schedule

Date	Significant Event
Mar 2022	CST – Assessment of pre-test prediction capabilities by using prediction validation tools in preparation of the Low-Boom Flight Demonstrator Validation Process.
Apr 2022	HyTEC – Completion of a Critical Design Review of a turbofan engine test to determine the impact of large-scale power extraction from both high- and low-pressure engine spools.

Date	Significant Event
Aug 2022	RVLT – Validation testing of hover performance for AAM aircraft noise and performance tool chain.
Sep 2022	RVLT – Completion of second generation AAM fleet operations noise assessment.
Sep 2022	HT – Development of tools for hypersonic design and decision making under uncertainty.
Nov 2022	CST – Completion of pre-flight capability review in preparation for the Low Boom Flight Demonstrator Validation Process.
Dec 2022	CST – Completion of acoustic validation measurement systems and plans needed for Low Boom Flight Demonstrator validation phase.
Jun 2023	HiCAM – Technology down-selection based upon coupon- and element-level assessments of technologies and technical concepts for continued research and advancement.
Sep 2023	AATT – Completion of a hybrid-electric powertrain demonstration with flight-like, flight weight components and a total power at least three times higher than state-of-the-art.
Sep 2023	RVLT – Conduct a workshop open to US industry to provide training for best-practice use of NASA-developed software for Advanced Air Mobility (AAM) performance and noise analysis.
Sep 2023	HyTEC – Completion of technology development testing for Phase 1 core technologies.
Sep 2023	HyTEC – Award of Phase 2 Core Demonstration contracts for core technology development and integration.

Program Management & Commitments

Program Element	Provider
Advanced Air Transport Technology (AATT)	Provider(s): ARC, AFRC, GRC, LaRC Lead Center: GRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): United States Air Force, Boeing, Pratt & Whitney, Northrop Grumman, General Electric Aviation, Aurora, United Technologies Corporation, Rolls Royce/Liberty Works, Honeywell, FAA, Lockheed Martin, United States. Navy, Department of Energy
Revolutionary Vertical Lift Technology (RVLT)	Provider(s): ARC, AFRC, GRC, LaRC Lead Center: LaRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): FAA, United States Army, United States Air Force, United States Navy, Raytheon Technologies Research Center, Moog Surefly, A&P Technologies, DLR, ONERA, QuesTek, Ohio State University--Gearlab and Smart Vehicle Concept Center, Pennsylvania State University – Applied Research Laboratory, University of Illinois--Power Optimization of Electro-thermal Systems, University of Maryland, Georgia Institute of Technology, National Research Council-Canada

Program Element	Provider
Commercial Supersonic Technology (CST)	Provider(s): ARC, GRC, LaRC, AFRC Lead Center: LaRC Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): Gulfstream Aerospace, FAA, JAXA, Rockwell Collins, ONERA, The University of Washington, Boeing Research and Technology, United States Navy
Hypersonic Technology (HT)	Provider(s): AFRC, GRC, LaRC Lead Center: LaRC Performing Center(s): AFRC, GRC, and LaRC Cost Share Partners: DoD, John Hopkins University/Applied Physics Laboratory, Hermeus, Stratolaunch, Boeing
Hi-Rate Composite Aircraft Manufacturing (HiCAM)	Provider(s):ARC, GRC, LaRC Lead Center: LaRC Performing Center(s):ARC, GRC, LaRC Cost Share Partners: FAA, Advanced Thermoplastic Composites Manufacturing, Aurora Flight Sciences, Boeing, Collins Aerospace, CGTech, Collier Aerospace, Convergent Manufacturing Technologies - US, Electroimpact, General Electric Aviation, Hexcel, Lockheed Martin, Northrop Grumman, Solvay, Spirit AeroSystems, Toray Advanced Composites, University of South Carolina, Wichita State University
Hybrid Thermally Efficient Core (HyTEC)	Provider(s): AFRC, ARC, GRC, LaRC Lead Center: GRC Performing Center(s): AFRC, ARC, GRC, LaRC Cost Share Partners: GE Aviation, Pratt & Whitney

Acquisition Strategy

AAVP research and technology spans from foundational research to integrated system capabilities. This broad spectrum necessitates the use of a variety of acquisition tools relevant to the appropriate work awarded externally through full and open competition. For all procurement actions, NASA strongly encourages collaboration among large companies, small businesses, and universities.

MAJOR CONTRACTS/AWARDS

AAVP awards multiple smaller contracts, which are generally less than $5 million and widely distributed across academia and industry, with a few exceptions. AAVP anticipates awarding larger contracts to support the HyTEC and HiCAM projects' large technology development and demonstrations.

ADVANCED AIR VEHICLES PROGRAM

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Expert Review	Oct 2021	The 12-month review is a formal independent peer review. Experts from other NASA programs and Government agencies report on their assessment of technical and programmatic risk and/or program weaknesses.	The Panel provided favorable reviews to the projects. The Panel also gave constructive comments and recommendations.	Oct 2022

INTEGRATED AVIATION SYSTEMS PROGRAM

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Low Boom Flight Demonstrator	97.3	74.6	**36.9**	15.3	0.0	0.0	0.0
Electrified Powertrain Flight Demonstration	76.9	86.2	**106.7**	85.7	28.4	23.6	13.0
Other Projects	64.5	97.8	**145.4**	186.0	255.6	272.8	309.3
Total Budget	**238.7**	**258.6**	**288.9**	**287.1**	**284.0**	**296.4**	**322.3**
Change from FY 2022 Budget Request			**30.3**				
Percent change from FY 2022 Budget Request			**11.7%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Pictured above is a scale model of the Transonic Truss-Braced Wing concept during testing in the Langley Research Center 14- by 22-Foot Wind Tunnel. Wind-tunnel testing with industry partners validates environmental benefits.

Flight research creates a bridge between fundamental research and a level of technology readiness that enables technology transfer to the aviation community. Specifically, flight research advances technology readiness to the levels required for incorporation of new technologies into future air vehicles and operational systems.

The focus of the Integrated Aviation Systems Program (IASP) is to demonstrate integrated flight vehicle concepts and technologies in a relevant flight environment and establish a level of maturity that enables these technologies' transition to the aviation community. To support this goal, IASP focuses on the rigorous execution of highly complex flight campaigns and related experiments for the benefit of the Nation and U.S. flying public. IASP flight campaigns support all research maturity levels and often facilitate cross-cutting flight test activities. For technologies at lower Technology Readiness Levels (TRLs), IASP flight research accelerates the technologies' development and determines the feasibility of maturing them further and transitioning them to operations. For technologies at higher TRLs, flight research reduces risks and accelerates transition of those technologies to industry.

IASP supports two critical cross-program efforts: Sustainable Flight National Partnership (SFNP) and the Low-Boom Flight Demonstration Mission. In support of SFNP, IASP leads the Sustainable Flight Demonstrator (SFD) and Electrified Powertrain Flight Demonstration projects. In relation to the Low-Boom Flight Demonstration Mission, IASP leads the Low-Boom Flight Demonstrator (LBFD) project to build, assemble, and conduct flight validation tests for the X-59 supersonic aircraft and will lead flight operations in support of the X-59 community response testing.

INTEGRATED AVIATION SYSTEMS PROGRAM

The Flight Demonstrations and Capabilities (FDC) project conducts integrated research demonstrations, which include the X-57 Maxwell aircraft and development of supersonic flight-testing techniques. Furthermore, FDC operates, sustains, and enhances flight test range and laboratory infrastructure required to test complex flight demonstrations. Funding for FDC and SFD is consolidated into the Other Projects line in the budget table above.

IASP directly supports two of the ARMD Strategic Thrusts:

- Thrust 2: Innovation in Commercial Supersonic Aircraft; and
- Thrust 3: Ultra-Efficient Subsonic Transports.

EXPLANATION OF MAJOR CHANGES IN FY 2023

NASA increased funding for the Sustainable Flight Demonstrator (SFD) project to increase confidence that it will deliver results to industry in a timely manner. The SFD will be a large-scale integrated flight demonstration with objectives to reduce fuel burn, emissions, and noise. This project is the centerpiece of NASA's Sustainable Flight National Partnership.

NASA will transfer the Advanced Air Mobility (AAM) project from the Integrated Aviation Systems Program to the Airspace Operations and Safety Program. The AAM project relies on air traffic management capabilities developed by AOSP. Therefore, this realignment will maximize the synergies between the AAM project and AOSP's current projects (ATM Exploration, System Wide Safety, and Advanced Capabilities for Emergency Response Operations).

ACHIEVEMENTS IN FY 2021

At the end of each achievement identified in this document, there is a parenthetical to link it to the related Strategic Research Thrust and Program Element.

- NASA developed tools and techniques to validate sonic boom signatures in preparation for X-59 flight operations. NASA conducted a flight test of a nose mounted shock sensing probe on the NASA F-15 that will measure LBFD shock wave structure. NASA conducted a successful in-flight demonstration of a pilot assisted aircraft positioning system that will allow the F-15 research aircraft to precisely position itself with respect to the X-59 aircraft for pressure measurements or airborne imaging. (Thrust 2/Flight Demonstrations and Capabilities [FDC])
- NASA made progress on the integration and testing of the all-electric X-57 Maxwell aircraft in preparation for first flight. The high-voltage ground testing completion paved the way for final verification and validation testing of the flight batteries, cruise motors, and software. In addition, the successful testing of cruise motor controller hardware and software occurred. The Mod III wing successfully completed fit check prior to removal from the spare fuselage. Lessons from the integration effort are influencing the development of electric aircraft propulsion standards. (Thrust 3/FDC)
- NASA awarded several risk reduction activity contracts with industry and is moving forward to develop and mature airframe technologies for the next generation of commercial single-aisle aircraft. (Thrust 3/Sustainable Flight Demonstrator [SFD])

INTEGRATED AVIATION SYSTEMS PROGRAM

WORK IN PROGRESS IN FY 2022

- In preparation for X-59 flight operations, NASA will deliver a validated F-15-based test capability that enables precise, near-field probing and airborne imaging of the LBFD shockwave structure. This capability ensures that the shockwave structure produced by the X-59 aircraft in flight is easily comparable with current simulations during the flight test campaign. (Thrust 2/FDC)
- NASA will conduct the first flight of the all-electric X-57 Maxwell aircraft. In conjunction with the flight test, NASA will support the development of manufacturing standards for electrified aircraft systems to enable progress for U.S. companies to develop more electric aircraft. (Thrust 3/FDC)

KEY ACHIEVEMENTS PLANNED FOR FY 2023

- NASA will conduct flight test operations in support of X-59 supersonic aircraft first flights. (Thrust 2/FDC)
- NASA will conduct Crossflow Attenuated Natural Laminar Flow (CATNLF) flight testing. CATNLF is a new design method that has the potential to enable natural laminar flow over the aircraft wings. (Thrust 2/FDC)
- NASA will award the contract for the Sustainable Flight Demonstrator project and continue formulation of the project. (Thrust 3/SFD)

Program Elements

The Electrified Powertrain Flight Demonstrations and Low-Boom Flight Demonstrator projects within IASP are lifecycle controlled and reported in separate sections.

FLIGHT DEMONSTRATIONS AND CAPABILITIES (FDC)

NASA's FDC project validates the benefits of various technologies and demonstrates the feasibility and maturity of new technologies through flight testing in a relevant environment. The flight experiments are campaigns focused on aggressive, success-oriented schedules utilizing the most appropriate set of assets available to accomplish experimental objectives, while leveraging collaborative opportunities (as appropriate) from across the aeronautical industry. While many of the technologies are at relatively high TRLs, the FDC project supports all phases of technology maturation. The FDC project also operates and maintains a support aircraft fleet that enables safety chase and in-flight experimental measurements in support of a variety of NASA missions.

One such flight experiment is NASA's first all-electric X-plane, the X-57 Maxwell. The X-57 effort will test and determine the airworthiness of electrified aircraft technologies, with strong applicability to a broad range of electric aircraft configurations. This effort will result in the development of applicable manufacturing standards and establishing certification pathways for electric aircraft, such as those needed for emerging advanced air mobility markets.

INTEGRATED AVIATION SYSTEMS PROGRAM

SUSTAINABLE FLIGHT DEMONSTRATOR (SFD)

One of the key components of the Sustainable Flight National Partnership is the SFD project. SFD will be a large-scale integrated flight demonstration with objectives to reduce fuel burn, emissions, and noise. The aircraft, notionally planned for flight in FY 2027, will deliver matured airframe technologies to industry for use in the next generation commercial transport aircraft.

Program Schedule

Date	Significant Event
May 2022	FDC – Complete ARMD Flight Data Portal Phase 1
Jun 2022	FDC – Complete X-57 Mod II First Flight
Aug 2022	FDC – F-15D Ready for LBFD
Aug 2022	FDC – Begin Schlieren Airborne Measurements and Range Operations in support of the X-59 aircraft flight operations
Oct 2022	SFD – Complete contract award
Dec 2023	FDC – Complete Crossflow Attenuated Natural Laminar Flow Flight Test

Program Management & Commitments

Program Element	Provider
Flight Demonstrations and Capabilities (FDC)	Provider(s): ARC, AFRC, GRC, LaRC Lead Center: AFRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): DoD, Air Force Research Laboratory, Lockheed Martin, ESAero
Sustainable Flight Demonstrator (SFD)	Provider(s): ARC, AFRC, GRC, LaRC Lead Center: HQ Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): TBD

Acquisition Strategy

IASP research and technology development focuses on integrated system capabilities. The program uses a variety of acquisition tools relevant to the appropriate work awarded externally through full and open competition. For all procurement actions, NASA strongly encourages teaming among large companies, small businesses, and universities.

INTEGRATED AVIATION SYSTEMS PROGRAM

MAJOR CONTRACTS/AWARDS

IASP awards multiple smaller contracts, which are generally less than $7 million and widely distributed across academia and industry for efforts supporting advanced air mobility and small-scale flight demonstrations. IASP awards substantially larger contracts for the design and build of large-scale flight demonstration (e.g., EPFD, SFD, and LBFD).

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Expert Review	Oct 2021	The purpose of the 12-month review is for tracking and documenting the projects' progress made towards the Strategic Thrusts and outcomes during the fiscal year.	The Review Panel acknowledged the projects laid out an outstanding record of accomplishment in FY 2021 despite challenges from COVID-19. There were no findings.	Oct 2022

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

FY 2023 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027	BTC	Total
Formulation	100.5	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	100.5
Development/Implementation	332.7	97.3	93.3	**48.9**	0.0	0.0	0.0	0.0	0.0	572.2
Operations/Close-out	0.0	0.0	0.0	**0.0**	24.4	0.0	0.0	0.0	0.0	24.4
2022 MPAR LCC Estimate	**433.1**	**97.3**	**93.3**	**48.9**	**24.4**	**0.0**	**0.0**	**0.0**	**0.0**	**697.0**
Total Budget	**433.1**	**97.3**	**74.6**	**36.9**	**15.3**	**0.0**	**0.0**	**0.0**	**0.0**	**657.3**
Change from FY 2022 Budget Request				**-37.7**						
Percent change from FY 2022 Budget Request				**-50.5%**						

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The 2022 MPAR LCC Estimate reflects the Fiscal Year 2022 Quarter 1 Financial Report, which is current as of December 2021. The requested budget authority is the project's current budget requirements which have seen programmatic changes approved by NASA since December 2021.

The difference between the 2022 MPAR LCC Estimate and the Total Budget line is the reserves.

Shown here is the X-59's eXternal Vision System, which is a forward-facing multi-camera that enables the pilot to "see" what is in front of the vehicle's elongated nose.

PROJECT PURPOSE

In order to open the market to supersonic flight over land, new environmental standards are needed. Over the past decade, fundamental research and experimentation has demonstrated the possibility of supersonic flight with greatly reduced sonic boom noise. The Low-Boom Flight Demonstrator (LBFD) project will demonstrate these advancements in flight by utilizing a purpose-built experimental aircraft designated the X-59 Quiet Supersonic Technology (QueSST). It will provide validation of design tools and technologies applicable to overcome the sonic boom noise barrier and open the door for the development of a new generation of environment-friendly, supersonic civil transport aircraft. The LBFD Mission will create a

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

database of community response information to support the development of a noise-based standard for supersonic overland flight.

The Advanced Air Vehicles Program (AAVP) and the Integrated Aviation Systems Program (IASP) co-lead the LBFD Mission. IASP's LBFD project provides the flight vehicle, IASP's Flight Demonstrations and Capabilities (FDC) project will conduct flight test operations with the X-59 vehicle, and AAVP's Commercial Supersonic Transport (CST) project will conduct the assessments of community responses to the X-59 vehicle low noise sonic boom. The LBFD project leads Phase 1 of the LBFD Mission, which includes the LBFD aircraft development activities. These activities start with the detailed design, continue through fabrication, and conclude with functional checkouts and supersonic envelope expansion. In Phase 2, a NASA-led team will perform low-boom acoustic validation flights of the X-59 aircraft. These flights will characterize and evaluate the near-field, mid-field, far-field, and ground sonic boom signatures from the X-59 aircraft. All three LBFD Mission projects (CST, LBFD, and FDC) will work collaboratively to conduct Phase 2 of the LBFD Mission. Following the completion of acoustic validation at the end of Phase 2, the LBFD project will conclude and the X-59 QueSST aircraft will transfer from the LBFD project team to the FDC project to conduct planned Phase 3 flight operations. For Phase 3, a NASA-led CST team will lead low-boom community response studies with multiple test flight campaigns using the LBFD aircraft over varied locations with aircraft operations conducted by the FDC project. In Phase 3, NASA researchers will gather data on public acceptance of the noise levels by flying over a handful of U.S. cities. In FY 2027, NASA will provide the finalized data to the Federal Aviation Administration and the International Civil Aviation Organization. Using this data, the regulatory organizations will be able to develop and adopt new rules to allow commercial supersonic flight over land. If a new standard is established, the U.S. aviation industry will be in position to lead the commercial supersonic market, and passengers will benefit from significantly shorter travel times.

EXPLANATION OF MAJOR CHANGES IN FY 2023

The LBFD project updated the costs and schedule based on Lockheed Martin's replan completed in July 2020. The replan addressed schedule delays due to contractor staffing and supplier issues and added an incentive fee plan to mitigate future delays. NASA also established processes for additional management oversight and insight into Lockheed Martin's performance in order to support on-schedule performance. The project reassessed their required reserves in June 2021 and proposed additional reserves to cover NASA costs due to the extended schedule and COVID impacts.

The October 2021 replan amendment for the first flight milestone moved from January 2022 to December 2022. The mission target for Phase 2 completion and transfer of the aircraft to FDC is August 2024.

PROJECT PARAMETERS

The LBFD project is responsible for building and flight validation of the X-59 QueSST aircraft. The X-59 aircraft is NASA’s newest experimental supersonic aircraft designed to reduce the sonic boom noise levels to a level acceptable to the general public. The vehicle will enable low-boom community response overflight studies with multiple test campaigns over varied U.S. locations as part of the LBFD

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

Mission. The mission ends in FY 2027 with the delivery of the final set of community response data to the International Civil Aviation Organization and the Federal Aviation Administration.

ACHIEVEMENTS IN FY 2021

NASA continued the integration of the X-59 aircraft. Lockheed completed integration of major components such as the nose, vertical tail, forebody, wing, and stabilators. In addition, the contractor completed subsystem updates on the fuel and hydraulics systems.

WORK IN PROGRESS IN FY 2022

NASA will complete the final assembly and system checkouts of the X-59 aircraft. The X-59 aircraft was shipped to a Lockheed Martin facility in Fort Worth, TX on December 31, 2021 in order to perform the ground proof loads test. The LBFD project will perform the air data probe calibration test in the Glenn Research Center (GRC) 8-foot by 6-foot wind tunnel and complete the emergency oxygen system testing. The X-59 aircraft will return to Palmdale, CA to undergo a series of ground tests including the ground vibration test, engine runs, and taxi tests. NASA will conduct a series of airworthiness and flight safety reviews of the X-59 supersonic aircraft in preparation for first flight, planned for December 2022.

NASA will complete contractor delivery of the subsystems (e.g., Flight Test Instrumentation System, Power Distribution System, engine, flight seats, and cockpit components) and all primary Government Furnished Equipment (GFE) required to develop the aircraft.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

NASA will complete airworthiness and flight testing of the X-59 supersonic aircraft in preparation for community response testing.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Baseline Date	FY 2023 PB Request
Key Decision Point-B (KDP-B)	Aug 2016	Aug 2016
Formulation Authorization	Sep 2016	Sep 2016
Acquisition Strategy Meeting	Nov 2016	Nov 2016
Preliminary Design Review (PDR)	Jun 2017	Jun 2017
Delta PDR	Jul 2018	Jul 2018
KDP-C	Oct 2018	Oct 2018
Critical Design Review	Aug 2019	Sep 2019
KDP-D	Oct 2019	Dec 2019

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

Milestone	Baseline Date	FY 2023 PB Request
Lockheed Re-Plan Complete	-	Jul 2020
Delta KDP-D	-	Jul 2020
X-59 Ship to LM Ft. Worth for Loads Test	Jul 2021	Dec 2021
Flight Readiness Review	Oct 2021	Sep 2022
First Flight Complete	Jan 2022	Dec 2022
System Acceptance Review (Phase 1) Flight Testing Complete	Jan 2023	Nov 2023
Acoustic Validation (Phase 2) Complete	Oct 2023	Aug 2024
Aircraft Transfer Review to FDC (Phase 2)	Oct 2023	Aug 2024
LBFD project Close-Out Complete	Apr 2024	Sep 2024

Development Cost and Schedule

The LBFD project completed a successful Delta KDP-D on July 15, 2020, and the project received authority to implement the updated cost and schedule profile. The LBFD project lifecycle includes aircraft concept refinement studies, aircraft preliminary design, aircraft final design and build, and acoustic validation flight testing. These activities span from FY 2014 to FY 2024 (Phase 1 and Phase 2 of the LBFD Mission).

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2018	467.7	70%	2022	572.2	+22%	First Flight	Jan 2022	Dec 2022	11

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time of development. Estimates that include combined cost and schedule risks denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**467.7**	**572.2**	**+104.5**
Flight Sciences	19.5	25.0	+5.5
Flight Systems	17.0	26.9	+9.9
Aircraft	230.9	352.1	+121.2
Aircraft Operations	45.1	57.8	+12.7
Other Direct Project Costs	155.2	110.4	-44.8

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Flight Sciences	Vehicle sonic boom, aerodynamics, propulsion, structures, and mission performance NASA in-house flight simulation tools, and analysis of vehicle handling qualities and control laws	Provider: Ames Research Center (ARC), Armstrong Flight Research Center (AFRC), Glenn Research Center (GRC), Langley Research Center (LaRC) Lead Center: LaRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): N/A	N/A
Flight Systems	Design, development, and test of Power Distribution System (PDS), Flight Test Instrumentation System (FTIS), and eXternal Vision System (XVS)	Provider: AFRC, LaRC Lead Center: AFRC Performing Center(s): AFRC, LaRC Cost Share Partner(s): N/A	N/A
Aircraft	Design, build and initial test of a single-piloted X-plane by the end of 2021	Provider: Lockheed Martin Lead Center: AFRC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Aircraft Operations	Demonstrate airworthiness of aircraft, flight operations, and develop key aircraft subsystems - including life support and crew escape systems Provide Government Furnished Equipment (GFE) to construct the research aircraft, support and maintain F414 engine, and perform insight/oversight of Ops-related tasks that the vehicle Contractor performs	Provider: AFRC, LaRC Lead Center: AFRC Performing Center(s): AFRC, LaRC Cost Share Partner(s)/subcontractors: GE, Northrop, Honeywell, and Lockheed Martin	N/A

Project Risks

Risk Statement	Mitigation
Sonic Boom Level is Not Acceptable for Community Overflight Research Given that achieving a fully shaped sonic boom ground signature in the 70-75 perceived decibel level (PLdB) range requires a complex and integrated design solution that is sensitive to outer mold line changes, there is a possibility that the mission requirements related to ground signature loudness may not be achievable - resulting in an aircraft that may not be fully acceptable for community response studies.	NASA will ensure that all configuration assessments use the latest and most mature aircraft configuration and periodically assess any updates to the aircraft configuration, such as the outer mold line or performance characteristics.
Reduced Aircraft Performance Could Impact Mission Effectiveness Given the aircraft and propulsion system selection and integration complexity, there is a possibility of reduced aircraft performance resulting in loss of mission effectiveness and leading to longer duration time to meet flight parameter(s), increased costs, and limitations of flight test points to standard-day conditions.	NASA will ensure that the contractor has sufficient margin for aircraft weight growth with propulsion configuration; assess contractor aircraft performance and thrust predictions (both computationally and experimentally) over the aircraft flight envelope; and perform a trade study on engine performance during demanding conditions.

LOW-BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

Acquisition Strategy

The acquisition strategy for LBFD is to acquire through an industry partner the detailed design/build/test of the experimental low-boom demonstrator aircraft. NASA will provide in-house support that will include in-flight and ground systems, instrumentation and operations, simulation, wind tunnel testing, and safety and mission assurance. NASA supplies aircraft components and systems as GFE whenever feasible and considered to add value to the development of the LBFD aircraft.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
LBFD Aircraft - Design, Build, and Initial Testing	Lockheed Martin	Palmdale, CA
F414-GE-100 Engine	General Electric Aviation	Lynn, MA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	LBFD Independent Review Board (IRB)	Jun 2017	PDR	Successfully Completed	Jul 2018
Performance	LBFD IRB	Jul 2018	Delta PDR, Assess readiness for KDP-C	Successfully Completed	Sep 2019
Performance	LBFD IRB	Sep 2019	CDR, Assess readiness for KDP-D	Successfully Completed	May 2022
Performance	LBFD Flight Readiness Review (FRR) Board	May 2022	FRR	TBD	N/A

ELECTRIFIED POWERTRAIN FLIGHT DEMONSTRATION

Formulation	Development	Operations

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**76.9**	**86.2**	**106.7**	**85.7**	**28.4**	**23.6**	**13.0**
Change from FY 2022 Budget Request			**20.5**				
Percent change from FY 2022 Budget Request			**23.8%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

This picture depicts a notional hybrid-electric powertrain demonstration single-aisle class aircraft.

PROJECT PURPOSE

The purpose of the Electrified Powertrain Flight Demonstration (EPFD) project is to mature integrated megawatt (MW)-class electrified powertrain systems and components, thereby accelerating the introduction of these systems to the U.S. commercial transport fleet. In collaboration with U.S. industry, NASA will design, build, integrate, and perform ground and flight-tests of MW-class powertrain systems. These new systems will reduce fuel consumption by up to five percent and reduce harmful emissions. EPFD is a critical component of the Sustainable Flight National Partnership and supports ARMD Strategic Thrust 3: Ultra-Efficient Subsonic Transport.

As the benefits of electrified aircraft propulsion technology become realized, electrified aircraft propulsion research and development should rapidly gain momentum and transition into production and operations. Electrified powertrain systems will provide significant benefits in terms of reduced fuel/energy consumption and emissions. Such advances could pave the way for more cost-effective commercial aviation, while also reducing adverse societal impacts.

Through industry collaboration, EPFD will:

- Demonstrate in-flight integration of MW-class electric powertrain, power distribution, and energy storage systems; and
- Identify and address technical barriers, integration risks, and regulatory and standards gaps associated with such systems.

ELECTRIFIED POWERTRAIN FLIGHT DEMONSTRATION

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

PROJECT PRELIMINARY PARAMETERS

EPFD is a technology demonstration project that will flight demonstrate and evaluate the performance of MW-class hybrid-electric propulsion system technologies for commercial aircraft. Incorporating this technology could lead to higher fuel efficiency, reduced noise and emissions, and lower operating costs for commercial aircraft. The EPFD project will reduce risks for key critical technologies and address specific gaps in regulations and standards associated with introducing electrified propulsion into commercial aircraft.

EPFD will mature MW-class electrified powertrain systems through flight demonstrations applicable to the short-haul, regional, or thin-haul market segments and accelerate the U.S. industry's readiness to introduce these innovative electrified systems into the next generation of aircraft. This acceleration may occur by:

- Contributing to the development of next generation commercial subsonic transports by focusing on integrated MW-class powertrain system technology;
- Focusing on next generation single-aisle (150-200 passenger seat class) commercial transport aircraft;
- Ensuring an appropriate mix of potentially disruptive concepts and commercial transport products; and
- Directly engaging U.S. industry to facilitate timely integrated MW-class electrified powertrain system development and transition from government to industry.

EPFD will conduct two integrated MW-class powertrain system flight demonstrations, identifying and addressing regulation and standards gaps in addition to identifying and retiring barrier technical and integration risks.

ACHIEVEMENTS IN FY 2021

EPFD successfully awarded two contracts for the ground and flight demonstrations of the integrated MW-class powertrain systems for subsonic aircraft: General Electric Aviation (GE) of Cincinnati, Ohio, was awarded $179 million to flight test the CT7-9B turboshaft engines on a modified Saab 340B testbed; and MagniX USA Inc of Redmond, Washington, was awarded $74.3 million to demonstrate systems on a Dash 7-Combi testbed. EPFD demonstrations will help to rapidly mature and transition integrated Electrified Aircraft Propulsion (EAP) technologies for introduction into the global fleet in the 2030s.

WORK IN PROGRESS IN FY 2022

The project will hold a Delta System Readiness Review (SRR) after completion of each industry team's SRR. Additionally, a project level Integrated Baseline Review (IBR) will be held, upon completion of the industries' IBRs. The project is planning to hold at least one flight partner Preliminary Design Review (PDR) in FY 2022.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

Upon completion of industries' respective lifecycle reviews, NASA will conduct the appropriate project level KDP to obtain authority to proceed to the follow-on life cycle phase. The project plans to hold the KDP-C in FY 2023 prior to entering the implementation phase.

ESTIMATED PROJECT SCHEDULE

Milestone	Formulation Authorization Document	FY 2023 PB Request
KDP-A	Jun 2020	Jun 2020
Acquisition Strategy Meeting (ASM)	Jul 2020	Jul 2020
System Readiness Review (SRR)	Sep 2020	Sep 2020
Key Decision Point (KDP-B)	Oct 2020	Oct 2020
Procurement Strategy Meeting (PSM)	Oct 2020	Oct 2020
Project Level Delta System Requirements Review GE SRR magniX SRR	TBD	Jul 2022 May 2022 May 2022
Project Level Integrated Baseline Review (IBR) GE IBR magniX IBR	TBD	Aug 2022 Jun 2022 Jun 2022
Preliminary Design Review (PDR) GE PDR magniX PDR	Feb 2022 - Aug 2022	Jul 2022 Nov 2022
KDP-C	Mar 2022	Dec 2022
Critical Design Review (CDR) GE CDR magniX CDR	Feb 2023 - Aug 2023	Mar 2023 Oct 2023
KDP-D	Jul 2023 - Jan 2024	Dec 2023

ELECTRIFIED POWERTRAIN FLIGHT DEMONSTRATION

Formulation	Development	Operations

Milestone	Formulation Authorization Document	FY 2023 PB Request
Flight Readiness Review (FRR) GE FRR magniX FRR	Nov 2023 - Jul 2024	May 2025 December 2024

**The EPFD project is still in formulation, and any updates to the schedule will occur at KDP-C.*

Formulation Estimated Life Cycle Cost Range and Schedule Range Summary

The formulation agreement documents project costs at approximately $340.3 million over the next five years during the design and build phase. The life cycle cost of $412 million includes pre-Formulation and Formulation costs and related technology maturation activities conducted by the Advanced Air Transport Technology project, which occurred between FY 2017 and FY 2020.

Life cycle cost estimates are preliminary. A baseline cost commitment does not occur until the project reaches KDP-C, which follows a non-advocate review and/or preliminary design review.

KDP-B Date	Estimated Life Cycle Cost Range ($M)	Key Milestone	Key Milestone Estimated Date Range
October 7, 2020	$312M - $470M	First Flight	Dec 2023-Aug 2024

Project Management & Commitments

The following section will be updated after industry contracts are awarded.

Element	Description	Provider Details	Change from Formulation Agreement
MW-class electric powertrain, power distribution, and energy storage systems.	Flight demonstration and evaluation of the performance of MW-class hybrid-electric propulsion system technologies for commercial aircraft.	Provider: ARC, AFRC, GRC, LARC Lead Center: HQ Performing Center(s): ARC, AFRC, GRC, LARC Cost Share Partner(s): General Electric and MagniX	N/A

ELECTRIFIED POWERTRAIN FLIGHT DEMONSTRATION

Formulation	Development	Operations

Project Risks

Assessment and mitigation of risks provides the project with the ability to understand the technical scope and associated risks to achieve a successful mission execution. EPFD's Risk Management Process, per NASA's Procedural Requirements 8000.4B, positions IASP and EPFD to be agile and responsive from Formulation through Implementation to enable achievement of the project's technical performance goals and objectives within the project's lifecycle cost and schedule.

During Phase A, EPFD's Risk Management Process identified and matured specific risks related to the MW-class powertrain flight demonstrations. During Phase B, the development of risk identification and mitigations occur. There are three risk working groups leading these efforts: technical (system and component); safety and mission assurance (including airworthiness); and cost, schedule, and acquisition. The EPFD project has a risk registry containing all active risks stored in a document management system. Mitigation plans will be developed and funded (where necessary) to mitigate technical, cost, schedule, and safety risks based on the likelihood and potential consequences.

By managing these risks during Formulation, the project can be proactive in reducing barriers to technology insertion and establish MW-class powertrain system performance by validating component-level designs and obtaining preliminary test data at the component- and subsystem-level.

The following tables shows the top risks and current mitigation steps:

Risk Statement	Mitigation
Constrained Supply Base for Critical Components Given that the performance requirements of critical components exceed those of standard, commercially available parts, there is the possibility that the engineering and manufacturing suppliers will not be able to supply these components on schedule/in budget, resulting in a schedule delay and/or cost increase.	Post contract award, begin composition and tracking of Master List of Critical Components and their proposed delivery dates for the period between October 2021 and September 2023.

Formulation	Development	Operations

Risk Statement	Mitigation
Contractor(s) May Not be Able to Provide Sufficient Test Data to Demonstrate Technology Maturation Given that NASA will execute ground and flight tests with Industry Partners through a contract, there is a possibility that the industry partner test plan will fulfill the contract requirements but not all the data requirements for project success, resulting in a lack of data to validate EAP technologies, mature those technologies, and make the project successful.	Define Data needed to measure performance against Key Performance Parameters (Vision Vehicle) and Technical Performance Measures (TPMs) (Flight Demonstrations); measure advancement of TRL levels of MW-class powertrains; measure progress against Barrier Technical Risk (Vision Vehicle) based on progress against related Specific Technical Risks (Flight Demonstrations) Define data needed to support regulations and standards. Define data needed to provide validation data for NASA and industry tools and research. The use of validation data will reduce uncertainty in model estimation of EAP system performance in configurations not previously developed, tested, and evaluated. The following programs/projects will help support this effort: Advanced Air Vehicles Program's Advanced Air Transport Technology and Hybrid Thermally Efficient Core projects, and Transformative Aeronautics Concepts Program's Transformational Tools and Technologies project and the EPFD team. Create a Data Management Plan (preliminary) to address the data identified in the previous steps. Be sure this coincides with the Technology Development Plan and requirements for a Master Measurement List. Communicate data needs to industrial partners through Data Requirements Descriptions.
Integrated MW-Class Powertrain System Fails to Meet Technical Performance Metrics Under Flight Environments Given that Integrated MW-Class Powertrain Systems are under development, there is a possibility that they will not meet the required Technical Performance Metrics under flight environments resulting in the need for additional development with associated schedule and cost impacts.	At each lifecycle review, Industry Partners provide estimated technical performance as part of proposal in response to the Technical Data Requirements and Reporting (TDRR) and expected environments as part of their Systems Requirements Document. Industry Partners provide final assessment of overall activity in response to the Technology Maturation Report.

Acquisition Strategy

The acquisition strategy for EPFD is to collaborate with U.S. industry to design, build, integrate, and perform ground and flight tests of MW-class powertrain systems.

To conduct the necessary ground and flight demonstrations, EPFD awarded two contracts using full and open competition. EPFD will conduct integrated ground and flight demonstrations of MW-class

Formulation	Development	Operations

electrified powertrain technologies and systems to identify and address electrified powertrain certification gaps during the ground-based and flight test demonstrations.

MAJOR CONTRACTS/AWARDS

The release of the Request for Proposal, proposal selection, and contract awards occurred during FY 2021.

Element	Vendor	Location (of work performance)
Electrified Powertrain	General Electric Aviation (GE)	Cincinnati, OH
Electrified Powertrain	magniX USA Inc.	Everett, WA
Aircraft Mod and Integration	General Electric Aviation (GE)	Manassas, VA
Aircraft Mod and Integration	magniX USA Inc.	Field Aerospace, OK
Flight Test	General Electric Aviation (GE)	Victorville, CA
Flight Test	magniX USA Inc.	Field Aerospace, OK

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	EPFD Independent Review Board (IRB)	Sep 2020	System Requirements Review (SRR)	Successfully completed	Jul 2022
Performance	EPFD IRB	Jul 2022	Delta SRR	TBD	Jun 2022 - Nov 2022
Performance	EPFD IRB	Jun 2022 - Nov 2022	Preliminary Design Review (PDR)	TBD	Mar 2023 - Oct 2023
Performance	EPFD IRB	Mar 2023 - Oct 2023	Critical Design Review (CDR)	TBD	Jun 2024 - May 2025
Performance	EPFD IRB	Jun 2024 - May 2025	Flight Readiness Review (FRR)	TBD	TBD
Performance	EPFD IRB	Jun 2024 - Feb 2025	Post-Flight Assessment Review(s) (PFAR)	TBD	N/A

TRANSFORMATIVE AERO CONCEPTS PROGRAM

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**129.7**	**148.0**	**155.9**	**158.0**	**158.0**	**163.0**	**176.6**
Change from FY 2022 Budget Request			**7.9**				
Percent change from FY 2022 Budget Request			**5.3%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

A NASA researcher is shown here operating an uncrewed vehicle during a wildland firefighting exercise. This demonstrates a system developed under TACP that can coordinate multiple elements of disaster response including unmanned vehicles.

The Transformative Aeronautics Concepts Program (TACP) cultivates multi-disciplinary, revolutionary concepts to enable aviation transformation. TACP fosters innovative solutions to aviation challenges by capitalizing on advancements in the aeronautics and non-aeronautics sectors to create new opportunities in aviation. One major goal of the program is to reduce or eliminate technical barriers and infuse revolutionary concepts into the aviation community.

TACP creates advanced and improved computational tools, technologies, and experimental capabilities for use by other aeronautics programs, industry partners, and Government collaborators.

TACP's activities offer flexibility for innovators to explore technology feasibility and provide the knowledge for radical transformation. The program creates an environment for researchers to try out new ideas, test their concepts, and learn lessons from unsuccessful experiments. TACP addresses the need for computational and experimental tools that are critical for supporting technology development and enabling aviation transformation. Therefore, TACP's investments are in brand-new areas that can provide paradigm-shifting analysis and experimental capabilities. To get buy-in and foster the rapid adoption of program research products, TACP aggressively engages both the traditional aeronautics community and new non-traditional entities through tailored collaborations.

EXPLANATION OF MAJOR CHANGES IN FY 2023

NASA increased funding for the development of beyond next-generation zero-emissions aircraft concepts and technologies through the highly successful University Leadership Initiative.

TRANSFORMATIVE AERO CONCEPTS PROGRAM

ACHIEVEMENTS IN FY 2021

At the end of each achievement identified in this document, there is a parenthetical to link it to the related Program Element. TACP achievements each support multiple thrusts, and hence, TACP is a widely cross-cutting program.

- NASA completed a Combustion and Emissions Analysis of Alternatives study specifically focused on combustion modeling for use in the Advanced Air Vehicle Program to further investigate reducing the time and costs associated with certifying sustainable aviation fuels. Working with industry, NASA developed a capability to predict the impact of new alternative fuels, which can save thousands of gallons of fuel and months of time during the fuel certification process by reducing or eliminating costly combustion tests. (Cross-cutting/Transformational Tools & Technologies [TTT])
- NASA developed human-autonomy teaming solutions for future new aviation applications, including simplified vehicle operations for urban air mobility (UAM) and remote supervisory operations for air cargo flights. (Cross-cutting/TTT)
- NASA developed advanced computational models to characterize materials, systems, and manufacturing processes, to enable an integrated approach toward vehicle design, manufacturing, and certification. NASA Research Announcement awards were used to help engage the university community in support of this research. These new models will promote full lifecycle health monitoring and rapid manufacturing processes that do not compromise quality. (Cross-cutting/TTT)
- NASA developed integrated acoustics analysis capabilities for electric Vertical Take-Off and Landing vehicles that will enable U.S. manufacturers to design quieter UAM vehicles. (Cross-cutting/TTT)
- NASA initiated the Data and Reasoning Fabric (DRF) activity to lead and guide reasoning and decision-making processes between aerial vehicles and ground-based systems to increase efficiency and safety of operations. A detailed investigation into the feasibility, desirability, and viability of the DRF activity includes reviewing the required decisions (or reasonings) for UAM aircraft based on diverse and dynamic data, looking at vehicle, airspace, weather, infrastructure, payload, and customer data. (Cross-cutting/Convergent Aeronautics Solutions [CAS])
- NASA began formulation of the first set of new activities under the CAS project including the decision-making processes between aerial vehicles and ground-based systems to increase efficiency and safety of operations. A detailed investigation into the feasibility, desirability, and viability of the DRF activity includes reviewing the required decisions (or reasonings) for UAM aircraft based on diverse and dynamic data, looking at vehicle, airspace, weather, infrastructure, payload, and customer data. (Cross-cutting/Convergent Aeronautics Solutions [CAS])
- NASA solicited a set of University Leadership Initiative (ULI) proposals that included a new topic focused on zero-emissions aircraft and that supports the goals of the Administration. (Cross-cutting/University Innovation [UI])
- NASA selected new ULI awards across 19 universities and 10 industry partners that address technical barriers inherent in achieving ARMD's strategic outcomes: (Cross-cutting/UI)
  - The University of Texas, Austin will develop methods that could validate the cost and scalability of conceptual autonomous cargo operations. They will provide theory and concepts for all types of vehicles — from large, unmanned cargo aircraft operating from coast to coast, to the single drone that can drop a package in a residential neighborhood.

TRANSFORMATIVE AERO CONCEPTS PROGRAM

- The Pennsylvania State University seeks to reimagine the aircraft propulsion system, including hybridization and optimizing and re-designing the core of the gas turbine engine, to explore the possibility of a safe, efficient, and innovative path to reduce the fuel consumption and lower the carbon footprint of the aviation industry.
- The University of California San Diego will combine multidisciplinary computational models of UAM vehicles and advanced design optimization algorithms for rapidly designing safe, quiet, efficient, and affordable UAM vehicle concepts.
- Georgia Tech will research and demonstrate ways to implement new structural materials, manufacturing techniques, and maintenance/repair processes for UAM vertical lift vehicles to make civilian applications achievable and profitable.
- NASA and the Air Force Office of Scientific Research (AFOSR) co-sponsored two ULI university awards to redefine sensing and analysis of hypersonic vehicles that can travel at least five times the speed of sound and potentially revolutionize space and air travel. The first award, to Purdue University and funded by NASA, will refine techniques and hardware associated with a particular set of optical and laser sensors that can be used in examining the surfaces and flow of a hypersonic vehicle in a way that can help that aircraft maintain control in flight. The second award, to the University of Texas at Austin and funded by AFOSR, is geared towards creating a new paradigm in sensing for hypersonic vehicles which may be applied to lower-speed vehicles. The project will treat the vehicles themselves as sensors, analyzing aerodynamic changes during flight tests, and use that information to infer where forces are being applied to protect and control the vehicles.

WORK IN PROGRESS IN FY 2022

- NASA will investigate new insulator and conductor materials to demonstrate a high voltage electrical bus-bar with a multifunctional electrical insulation system for the Fundamental Electrified Aircraft Propulsion subproject. This effort will aim to develop and validate innovative materials, tools, and methods for next-generation electric and hybrid-electric aircraft. (Cross-cutting/TTT)
- NASA will continue development under the Revolutionary Aviation Mobility (RAM) activity on a Multi-disciplinary Design, Analyses, and Optimization (MDAO) of human interactive studies for operation of autonomous aircraft fleets. An assessment of intelligent contingency management methods for a selected hazard, such as lost link or loss of control of the aircraft, will be performed, and a ground control station capable of managing beyond-visual-line-of-sight aircraft will be delivered to the Advanced Air Mobility (AAM) project in the Airspace Operations and Safety Program. (Cross-cutting/TTT)
- NASA will complete the first juncture flow experiments for validating efficient, eddy-resolving computational modeling tools to predict the maximum lift coefficient for transport aircraft during take-off and landing. These experiments will utilize new innovative measurement techniques currently under development for measurements of on- and off-body flow and begin investigation of icing effects on transport aircraft. (Cross-cutting/TTT)
- NASA will complete feasibility assessments on two CAS activities: Scalable Traffic Management for Emergency Response Operations (STEReO) and Fit2Fly. The STEReO activity will create a UTM ecosystem that can reduce response times, scale aircraft operations, and provide operational resiliency to active changes during a disaster. The Fit2Fly activity will produce concepts to assure operators of commercial drone fleets that vehicles are able to fly using automated inspection and digital

TRANSFORMATIVE AERO CONCEPTS PROGRAM

airworthiness certificates. This concept will create an auditable system determining whether aircraft have enough reliability to perform their intended missions. (Cross-cutting/CAS).

- NASA will extend research efforts on existing awards for the University of Illinois and Ohio State University to continue their zero-emissions activities in coordination with the Advanced Air Vehicles and Integrated Aviation Systems Programs. The University of Illinois will continue to develop liquid hydrogen fuel cells and a superconducting electrical system to power an electrically driven aircraft, and the Ohio State University will continue to create advanced motors and electronic power systems supporting electric propulsion aircraft. (Cross-cutting/UI)
- NASA will make additional ULI award solicitations to address NASA Aeronautics Strategic Implementation Plan and include zero-emission topics. (Cross-cutting/UI)

KEY ACHIEVEMENTS PLANNED FOR FY 2023

- NASA will conduct validation tests in the National Transonic Facility (NTF) and risk reduction experiments in the Basic Aerodynamic Research Tunnel (BART) facility pertaining to Reduced Life Cycle Cost (RLCC) subproject. NASA will use innovative measurement techniques to investigate computational tools for prediction of maximum lift and use uncertainty quantification to demonstrate adaptive mesh capability for unsteady scale resolving simulations. (Cross-cutting/TTT)
- NASA will complete acoustic perception-influenced validation experiments of MDAO in the Low-Speed Aeroacoustic Wind Tunnel. NASA will use rapid aerodynamic modeling methods to develop the Georgia Tech research aircraft and to baseline flight control laws. (Cross-cutting/TTT)
- NASA will complete two CAS activities: solid-state additively manufactured batteries for enhanced energy, recharging, and safety; and sensor-based prognostics to avoid runaway reactions and catastrophic ignition. (Cross-cutting/CAS)
- NASA will award new ULI proposals under the UI project. Proposals will address additional technical barriers intrinsic to achieving ARMD’s strategic outcomes. NASA anticipates that new awards will include investment in research for zero-emissions aviation for the future. (Cross-cutting/UI)
- NASA will close and evaluate several current ULI awards: (Cross-cutting/UI)
  - Texas A&M University: Reduction of supersonic noise for various atmospheric conditions by changing the aircraft outer mold line.
  - University of Tennessee: Improvement of aerodynamic efficiency of slotted natural laminar flow aircraft.
  - Arizona State University: Improvement of risk prediction of the National Airspace System with information fusion and prognostics.
  - Carnegie Mellon University: Investigation of a scientifically sound basis for qualifying additive manufacturing and demonstrating an ecosystem for efficient large-scale production.
  - University of Wisconsin, Madison: Investigation of new methods in which humans can use robotics to improve the efficiency and flexibility of aviation-related manufacturing processes that enhances the safety of human workers.

TRANSFORMATIVE AERO CONCEPTS PROGRAM

Program Elements

CONVERGENT AERONAUTICS SOLUTIONS (CAS)

The CAS project performs rapid feasibility assessments of early-stage innovations that challenge existing technical approaches, create alternate paths to solutions, and enable new strategic outcomes. The project focuses on merging traditional aeronautics disciplines with advancements driven by the non-aeronautics world to overcome barriers and enable new capabilities in commercial aviation. Internal research teams conduct initial feasibility studies, perform experiments, try out new ideas, and identify and learn from failures. When a review determines that the developed solutions have met their goals and identified potential for future aviation impact, ARMD considers the most promising capabilities for continued development by other programs or by direct transfer to the aviation community.

TRANSFORMATIONAL TOOLS AND TECHNOLOGIES (TTT)

The TTT project advances state-of-the-art computational and experimental tools and technologies that are vital to aviation applications in the six strategic thrusts. These new computer-based tools, models, and associated scientific knowledge provide first-of-a-kind capabilities to analyze, understand, and predict performance for a variety of aviation concepts. Applying these tools will enable and accelerate NASA's research and enable the aviation community to introduce advanced concepts and designs. An example includes, the development and validation of new computational tools used to predict complex turbulent airflow around vehicles and within propulsion systems; ultimately leading to an improved ability to predict future vehicle performance in flight. The project also explores technologies that are critical to advancing ARMD strategic outcomes, such as understanding new types of strong and lightweight materials, innovative aircraft control techniques, and experimental methods. Such technologies will support and enable concept development and benefit assessment across multiple ARMD programs and disciplines. TTT has an Autonomous Systems sub-project to explore new capabilities to enable improved performance and safety of innovative autonomous aircraft and their operational controls.

UNIVERSITY INNOVATION (UI)

The UI project contains a portfolio of disruptive technologies, and other new concepts, to meet the goals established by the ARMD strategic thrusts, and support education of the next generation of engineers. The project utilizes NASA Research Announcement solicitations where university-led teams assess the most critical technical challenges to solve to achieve the Strategic Implementation Plan strategic outcomes; and propose independent, innovative research projects to solve those technical challenges. Universities develop their own success criteria, progress indicators, and technical approaches. Universities pursue multi-disciplinary approaches and incorporate opportunities with other universities, industry, and U.S. entities.

TRANSFORMATIVE AERO CONCEPTS PROGRAM

PROGRAM SCHEDULE

Date	Significant Event
Mar 2022	UI – Plan to release ULI Round 6 Solicitation
Jul 2022	UI – Award ULI Round 5 Selections
Aug 2022	TTT – Fly second-generation deployable vortex generator system on Boeing's EcoDemonstrator
Sep 2022	TTT – Deliver validated set of coupled, variable-fidelity, multidisciplinary design, analysis, and optimization (MDAO) tools enabling assessment of non-conventional air vehicles, including electric urban air mobility aircraft
Sep 2022	CAS – Close out/transition of High-Efficiency Electrified Aircraft Thermal Research
Sep 2022	UI – Plan Final Annual Reviews of ULI Round 1 Selections for University of Tennessee, Knoxville, and Texas A&M University
Dec 2022	CAS – Close out/transition of Solid-state Additively-manufactured Batteries for enhanced Energy, Recharging, and Safety
Mar 2023	UI – Plan to release ULI Round 7 Solicitation
Mar 2023	CAS – Close out/transition of Sensor-based Prognostics to Avoid Runaway Reactions & Catastrophic Ignition
Jun 2023	CAS – Close out/transition of Data and Reasoning Fabric
Jul 2023	UI – Award ULI Round 6 Selections
Aug 2023	UI – Plan Final Annual Reviews of ULI Round 1 Selections for Ohio State University and Arizona State University
Sep 2023	TTT – Deliver first high lift common research model wind tunnel test in the National Transonic Facility
Sep 2023	TTT – Complete development of aerodynamic model for the Georgia Tech research aircraft in the Low Speed Aeroacoustic Wind Tunnel

PROGRAM MANAGEMENT & COMMITMENTS

Program Element	Provider
Convergent Aeronautics Solutions (CAS)	Provider(s): ARC, GRC, LaRC, AFRC Lead Center: HQ Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): PCKrause & Associates, National Institute of Aerospace, Boeing, ESAero, Launch Point, Straight Up Imaging, DoT Volpe, Moog Inc., IDEO, Idea Couture, Tecolote Research Inc.

TRANSFORMATIVE AERO CONCEPTS PROGRAM

Program Element	Provider
Transformational Tools and Technologies (TTT)	Provider(s): ARC, GRC, LaRC, AFRC Lead Center: GRC Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): Boeing, Pratt & Whitney, Rolls Royce, Honda, UTRC, ESI, Blue Quartz Software, General Electric, DoD, Honeywell, BAE Systems, UTC Aerospace Systems, Ohio Aerospace Institute, U.S. small businesses
University Innovation (UI)	Provider(s): ARC, GRC, LaRC, AFRC Lead Center: HQ Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): N/A

ACQUISITION STRATEGY

TACP research and technology development focuses on foundational research capabilities. The program uses of a variety of acquisition tools relevant to the appropriate work awarded externally through full and open competition. For all procurement actions, NASA strongly encourages teaming among large companies, small businesses, and universities.

MAJOR CONTRACTS/AWARDS

TACP awards multiple smaller contracts, which are generally less than $5 million, and widely distributed across academia and industry.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Expert Review	Oct 2021	The 12-month review is a formal independent peer review. Experts from other Government agencies report on their assessment of technical and programmatic risk and/or project weaknesses.	Received expert feedback on project improvement from the Panel. Determined that the projects made satisfactory progress in meeting objectives.	Oct 2022

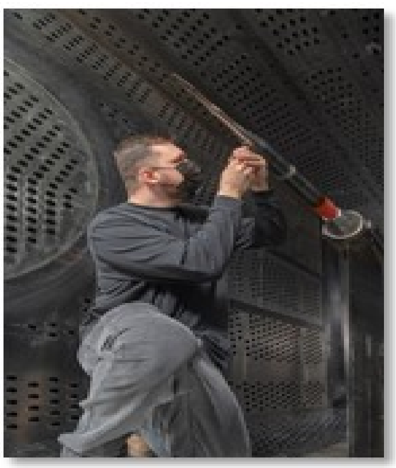
AEROSCIENCES EVALUATION AND TEST CAPABILITIES

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**116.9**	**117.0**	**117.3**	**117.3**	**117.3**	**117.3**	**119.9**
Change from FY 2022 Budget Request			**0.3**				
Percent change from FY 2022 Budget Request			**0.3%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



Pictured above is the Glenn 8 x 6 Supersonic Wind Tunnel Air Data Probe Calibration Test for the X-59 Low-Boom Flight Demonstrator (LBFD) project.

The Aerosciences Evaluation and Test Capabilities (AETC) Portfolio sets the strategic direction and funds operations, maintenance, and upgrades of NASA's versatile and comprehensive portfolio of aerosciences ground-test capabilities and assets. Among these assets are subsonic, transonic, supersonic, and hypersonic wind tunnels, propulsion test facilities, and specialty tunnels at the Ames Research Center (ARC), Glenn Research Center (GRC), and Langley Research Center (LaRC). NASA's integrated approach to test capability planning, use, and management also considers complementary computational tools, software, and related systems to effectively acquire and process research data.

Through broad alliances outside of NASA, AETC optimizes the use of these capabilities across the Government. NASA participates in the National Partnership for Aeronautical Testing and collaborative working groups that include NASA, the Department of Defense (DoD), and other partners. Members of these working groups: (1) gain awareness of capabilities across the Government, academia, and industry; (2) share best practices; (3) provide technical support; and (4) refer test programs to facilities best suited to meet test requirements.

Within NASA, AETC directly supports the testing needs of five mission directorates: Aeronautics Research Mission Directorate, Exploration Systems Development Mission Directorate, Space Operations Mission Directorate, Science Mission Directorate, and the Space Technology Mission Directorate.

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

AEROSCIENCES EVALUATION AND TEST CAPABILITIES

ACHIEVEMENTS IN FY 2021

- AETC wind tunnels supported testing and new capability investments, albeit at reduced levels due to the COVID-19 pandemic. Approximately half of the normal annual tunnel utilizations supported various NASA mission testing needs, including those related to advanced aircraft concepts, future space exploration mission vehicle developments (e.g., Space Launch System [SLS], Orion), planetary entry system modeling, external customer tests, and multiple classified tests in support of national security efforts. Specifically, AETC supported:
  - SLS Liftoff Test (Langley 14x22 Foot Subsonic Wind Tunnel);
  - SLS Cargo Test (Langley Unitary Plan Wind Tunnel);
  - Aeroshell-Drogue Parachute System Test (Langley Vertical Spin Tunnel (Langley VST)) for Dragonfly Mission to Titan;
  - Mars Sample Return Earth Entry Vehicle Test (Langley VST);
  - Low-Boom Flight Demonstrator Air Data Probe Calibration Test (Glenn 8x6 Foot Supersonic Tunnel); and
  - Transonic Truss-Braced Wing Test (Langley 14x22 Foot Subsonic Wind Tunnel), in addition to several other test campaigns.
- The National Transonic Facility (NTF) upgraded its obsolete drive control system for the 101-megawatt, 135,000 horsepower main drive motor.
- AETC documented an operational, controllable, and calibrated icing capability of the Propulsion Systems Laboratory to address issues for future full-scale engine and component tests.

WORK IN PROGRESS IN FY 2022

- AETC is transitioning back to full operations of all 12 of NASA's large wind tunnels. AETC is providing wind tunnel support for various Agency mission testing needs including advanced aircraft concepts, future space exploration mission vehicle developments, planetary entry system modeling, external customer tests, and multiple classified tests in support of national security activities.
- AETC continue to advance integration of Computational Fluid Dynamics (CFD) and experimental testing, which will allow more efficient, optimized testing for all customers, and provide a strong basis in future capability sustainment. AETC will complete an assessment of the accuracy and efficiency of computational analysis compared to the LaRC Unitary Plan Supersonic Wind Tunnel experimental data across multiple CFD models having a wide spectrum of aerodynamic prediction challenges. NASA will use methods learned from this assessment in future wind tunnel assessments.
- AETC will deploy a new propulsion simulation calibration and testing capability for aircraft and spacecraft models at the NASA Langley National Transonic Tunnel. This new capability enables acquisition of next generation aerodynamic test data from aircraft and spacecraft models that integrate with propulsion simulators (e.g., air ejection nozzle or air-powered turbine propulsion simulators).
- AETC will complete fabrication and installation and enter into service a new Mach 6 nozzle in the LaRC 8-foot High-Temperature Tunnel. The upgraded wind tunnel will provide high-fidelity, true enthalpy, and true pressure Mach 6 test environments for durations of up to five minutes required to meet future NASA and DoD hypersonic vehicle ground test requirements.

AEROSCIENCES EVALUATION AND TEST CAPABILITIES

KEY ACHIEVEMENTS PLANNED FOR FY 2023

- AETC wind tunnels will support NASA's various mission testing needs including those related to advanced aircraft concepts, future space exploration mission vehicle developments, planetary entry system modeling, external customer tests, and multiple classified tests in support of national security requirements.
- AETC will assess the condition and health of testing capabilities at ARC, GRC, and LaRC. The review will identify equipment with a high-risk of failure due to age or maintenance issues.
- AETC will deploy a new propulsion simulation calibration and testing capability for aircraft and spacecraft models at the ARC Unitary Plan Wind Tunnel. This new capability enables acquisition of next generation aerodynamic test data from aircraft and spacecraft models that integrate with propulsion simulators (e.g., air ejection nozzle or air-powered turbine propulsion simulators).
- A new state-of-the-art system to measure, assess, and visualize unsteady aerodynamics for advanced and complex aerospace vehicles at high-resolution and unprecedented data turn-around times will be available at the Ames Unitary Plan Wind Tunnel with future applications at other tunnels.

Program Element

AEROSCIENCES EVALUATION AND TEST CAPABILITIES (AETC)

Aerosciences ground-test capabilities (e.g., facilities, systems, workforce, and tools) that support future aircraft, space vehicles, and operations require efficient and effective investment, operations, and management. Efforts in this area preserve and enhance ground test capabilities necessary to achieve the Agency's multi-Mission requirements. Among these assets are subsonic, transonic, supersonic, and hypersonic wind tunnels and propulsion test facilities at the Ames Research Center in Mountain View, CA, the Glenn Research Center in Cleveland, OH, and the Langley Research Center in Hampton, VA. These test facilities and capabilities also serve the needs of non-NASA users. NASA's integrated approach to test capability planning, use, and management will consider the complementary computational tools, software, and related systems to effectively acquire and process research data. NASA offers research customers high-quality data that accurately reflects the simulated test environment and the interactions of test articles in those test environments. Furthermore, NASA expertise helps ensure safe and successful use of the assets and the high quality of research outcomes. The portfolio is cross-cutting and supports the Aeronautics Research Mission Directorate's Strategic Thrusts, as well as other Agency efforts and those of key industry partners.

Program Schedule

Date	Significant Event
Jan 2022	AETC – Completion of capability for a full life cycle Mach 6 testing at long durations for NASA LaRC 8-foot High-Temperature Tunnel
Sep 2022	AETC – Completion of report on the evaluation of CFD for testing at high supersonic speeds at LaRC Unitary Wind Tunnel
Nov 2022	AETC – Completion of ARC and LaRC Propulsion Simulator Calibration Facility

AEROSCIENCES EVALUATION AND TEST CAPABILITIES

Date	Significant Event
Sep 2023	AETC - New state-of-the-art system to measure, assess, and visualize unsteady aerodynamics

Program Management & Commitments

Program Element	Provider
Aerosciences Evaluation and Test Capabilities (AETC)	Provider: ARC, LaRC, GRC Lead Center: HQ Performing Center(s): ARC, LaRC, GRC Cost Share Partner(s): Multiple

Acquisition Strategy

AETC uses of a variety of acquisition tools relevant to the appropriate work awarded externally through full and open competition. For all procurement actions NASA strongly encourages teaming among large companies, small businesses, and universities.

Major Contracts/Awards

AETC awards multiple smaller contracts, which are generally less than $5 million, and are typically with industry, which provide systems applicable to the sustainment and operations for large-scale wind tunnel assets.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome	Next Review
Performance	Expert Review	Nov 2021	This 12-month review is a formal independent peer review. Experts from other NASA missions and the DoD report on their assessment of technical and programmatic risk and/or program weaknesses.	This was a very favorable review. The Expert Reviewers encouraged the team to continue improving its processes including those that support operational efficiency gains and improved investment and divestment decision making.	Nov 2022

STEM ENGAGEMENT

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
NASA Space Grant	51.0	57.0	**57.0**	57.0	57.0	57.0	57.0
Established Program to Stimulate Comp Research	26.0	26.0	**26.0**	26.0	26.0	26.0	26.0
Minority University Research Education Program	38.0	48.0	**48.1**	48.1	48.1	48.1	48.1
Next Gen STEM	12.0	16.0	**19.1**	22.1	25.2	28.3	31.5
Total Budget	**127.0**	**147.0**	**150.1**	**153.1**	**156.2**	**159.3**	**162.5**
Change from FY 2022 Budget Request			**3.1**				
Percent change from FY 2022 Budget Request			**2.1%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

STEM ENGAGEMENT

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
NASA Space Grant	51.0	57.0	**57.0**	57.0	57.0	57.0	57.0
Established Program to Stimulate Comp Research	26.0	26.0	**26.0**	26.0	26.0	26.0	26.0
Minority University Research Education Program	38.0	48.0	**48.1**	48.1	48.1	48.1	48.1
Next Gen STEM	12.0	16.0	**19.1**	22.1	25.2	28.3	31.5
Total Budget	**127.0**	**147.0**	**150.1**	**153.1**	**156.2**	**159.3**	**162.5**
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Pictured here is a montage of students from NASA's 2020 internships program cohort. These students participated virtually during the pandemic with exciting projects and experiences.

NASA makes vital investments in Science, Technology, Engineering, and Mathematics (STEM) engagement, in direct alignment with NASA's 2022 Strategic Plan and Goal 4.3 to "build the next generation of explorers," as well as the Administration's priority of building a future diverse STEM workforce. The Office of STEM Engagement (OSTEM) leads the Agency's STEM engagement function, providing strategic guidance and charting direction in partnership with the mission directorates. OSTEM will also manage the STEM Engagement Program.

The scope of NASA STEM Engagement comprises all endeavors to attract, engage, and educate students and to support educators and educational institutions. STEM Engagement encompasses a broad and diverse set of programs, projects, activities, and products. This includes student internships and fellowships; student learning opportunities (e.g., challenges and competitions, camps, and other hands-on and virtual experiences); informal education and out-of-school learning activities; educational products, tools, and platforms; educator and faculty support; competitive grants and cooperative agreements to educational institutions for research and development and institutional support; and strategic partnerships with organizations to expand reach and impact.

NASA will continue to support Federal STEM education priorities and drive strategic alignment of the Agency's STEM engagement efforts through the NASA Strategy for STEM Engagement (https://www.nasa.gov/sites/default/files/atoms/files/nasa-strategy-for-stem-2020-23-508.pdf) via three strategic goals:

1. Create unique opportunities for a diverse set of students to contribute to NASA's work;
2. Build a diverse future STEM workforce by engaging students in authentic learning experiences with NASA's people, content, and facilities; and
3. Attract diverse groups of students to STEM through learning opportunities that spark interest and provide connections to NASA's mission and work.

These goals, along with their corresponding objectives and strategies, guide the Agency's STEM engagement efforts and are complemented by five design principles -- (1) mission-driven authentic STEM experiences, (2) evidence-based practices, (3) scalability, (4) outcome-driven, and (5) diversity and inclusion -- that guide the planning and execution of work in direct support of achieving the strategic goals.

OSTEM is accountable for the management of NASA's STEM Engagement Program, composed of four projects: National Space Grant College and Fellowship Project (Space Grant); Established Program to Stimulate Competitive Research (EPSCoR); Minority University Research and Education Project (MUREP); and Next Generation STEM Project (Next Gen STEM). These projects are outlined in detail in subsequent sections.

NASA will continue work begun in FY 2022 to advance its work around three priority focus areas:

- First, NASA will implement strategies to broaden student participation to increase diversity, equity, and inclusion in STEM through NASA opportunities and activities. NASA will continue to foster a culture and commitment across the STEM engagement community, including its grantees, partners, and collaborators, to broaden student participation through implementation of an action plan that was developed in FY 2021.
- Second, NASA will continue to build productive strategic partnerships and networks, expanding NASA's STEM ecosystem to magnify reach and impact. This will be accomplished through establishing formal partnerships with organizations through Space Act Agreements, in order to scale activities and expand results and impact, capitalizing on existing networks and distribution systems to deploy products and opportunities.
- Third, NASA will expand contributions in engaging K-12 students in STEM pathways, with an approach toward a continuum of experiences. This will include efforts to increase the accessibility and navigability of NASA opportunities and products for students and educators.

CONTRIBUTIONS TO NASA STRATEGIC AREAS:

The STEM Engagement Program, through a diverse set of efforts and activities, will continue to make direct contributions to FY 2023 strategic key investment areas:

Exploration and Leadership:

The STEM Engagement Program develops and implements a variety of efforts devoted to building the next generation workforce, essential to our nation's future capacity to lead cutting edge research and development, and conduct innovative and challenging efforts in space, including Earth and space science, technology, and exploration. Space Grant, MUREP, EPSCoR and Next Gen STEM, all will continue to provide student experiential learning opportunities to support students on STEM pathways, preparing them to enter the STEM workforce. In addition, the STEM Engagement Program will continue to make direct investments in student and faculty research through competitive opportunities. EPSCoR provides its diverse set of competitive opportunities, which are directly aligned with Agency mission needs and priorities. MUREP provides a set of research development activities including the MUREP Institutional Research Opportunity (MIRO), MUREP Space Technology Artemis Research (M-STAR), and High-Volume Manufacturing opportunities, to enable Minority Serving Institutions (MSIs) to become more competitive by growing their capacity in key global areas.

Climate Change Research:

The STEM Engagement Program will continue to provide opportunities for students and educational institutions to contribute to NASA's efforts in climate change research. For example, MUREP executes the Ocean Biology and Biogeochemistry, or OCEAN, activity to increase the capacity of MSIs in Earth Science and Climate related research. This collaboration with the Science Mission Directorate (SMD) allows principal investigators from MSIs to connect with the Science Team on key climate issues. In addition, EPSCoR competitive opportunities cultivate research and developmental activities that contribute to climate change efforts. For instance, EPSCoR has teamed with the U.S. Navy to study the impact of climate change on the oceans, and with the U.S. Army's Cold Region Research and Engineering Labs (CRREL) to research snow and ice concerns. Finally, Space Grant also enables direct contributions to climate change research at the state-level through its consortia. In FY 2022, fifteen Space Grant consortia funded competitive projects within their states specifically addressing climate change.

Equity and Inclusion:

The STEM Engagement Program directly furthers NASA's work toward broadening student participation to increase diversity, equity, and inclusion in STEM through learning opportunities and activities. NASA will continue to provide resources to Space Grant, supporting its work in engaging underserved and underrepresented students through a diverse set of activities within their consortia. This includes student learning activities, competitive research and development opportunities, and student work experiences. Space Grant will also focus on reaching underserved and underrepresented middle and high school students through hands-on, experiential learning activities conducted by a coalition of Space Grant consortia (initiated in FY 2022). MUREP devotes the entirety of its portfolio of investments toward increasing equity and inclusion, through resources that enable MSI student learning and growth, as well as investments to support capacity building of MSIs. EPSCoR furthers capacity and development of eligible jurisdictions. Finally, Next Gen STEM seeks to further equity and inclusion for K-12 students, as well as formal and informal educators, through all of its initiatives, which leverage the exciting work of NASA's missions to engage students in STEM learning and improve STEM identity and efficacy. Next Gen STEM employs evidence-based strategies and effective partnerships to reach students from populations historically underserved and underrepresented in STEM and to help them "see themselves in STEM". NASA also furthers equity and inclusion in STEM through the NASA internships program.

EXPLANATION OF MAJOR CHANGES IN FY 2023

The proposed Budget provides a $3 million increase (relative to the FY 2022 request) for Next Gen STEM to enhance critical investments in K-12. NASA will build on new initiatives begun in FY 2022 to implement a framework for K-12 that includes scalable learning activities and products in collaborations with partners, as well as cross-cutting elements devoted to serving educators and educational institutions. NASA will continue to implement an evidence-driven approach for K-12, relying on performance and evaluation data and targeted studies to design and evolve its strategy and approach. In FY 2023, NASA will further an intentional design and deployment approach via networks and connections within the educational ecosystem, including relationships with state STEM education organizations and informal education networks to better understand educator needs and better develop and deploy opportunities. NASA will also focus sparking STEM interest and attracting students to STEM, through NASA-unique learning opportunities to attract students, incremental learning activities to enable STEM student pathways, and immersive, experiential learning opportunities to prepare for STEM pursuits. For effective delivery of opportunities, NASA will focus on a system to improve access and use of NASA activities and resources.

In FY 2023, NASA will continue to expand opportunities for students, educators, and educational institutions that further mission directorates priorities, leveraging STEM engagement program investments.

WORK IN PROGRESS IN FY 2022

In FY 2022, OSTEM continues Agency-wide coordination in support of Agency and Federal Government priorities, to attract, engage, and educate students toward building a future STEM workforce. OSTEM continues to implement enterprise initiatives to improve efficiency and strengthen standards and rigor in program management, fiscal accountability, and performance measurement. In FY 2022, NASA will continue to implement a mission-driven STEM Engagement Program through its four projects. Details regarding project plans and activities are provided in dedicated subsequent sections.

In FY 2022, NASA's STEM Engagement enterprise is committed to implementing the following:

- Drive strategic alignment and a mission-driven programmatic model. This includes conducting a comprehensive analysis of the portfolio and building on programmatic efforts established in partnership with the mission directorates.
- Implement cross-cutting strategies to more effectively reach and serve students, educators, and educational institutions, and to improve operations.
  - NASA will continue to evolve and enhance the new STEM Gateway, replacing an outdated performance measurement system with a single platform integrating student registration, functional management, and performance measurement and analytics.
  - NASA will also continue to further its work in significantly enhancing its digital footprint to better reach students, including improved products at https://stem.nasa.gov.
  - NASA will continue to drive progress on the Agency internships program, with objectives for growth and enhanced student experiences.
  - NASA will also continue implementation of a partnerships strategy, cultivating new partnerships to increase reach and impact.
  - Finally, NASA will continue to implement and build upon the STEM Engagement Performance Assessment and Evaluation Learning Agenda and conduct a set of studies to inform evidence-based program changes.
- Focus on broadening student participation. NASA will continue implementation of an integrated action plan toward broadening student participation in STEM engagement programs and activities.

- Further an enterprise operating model and focus on building skills and capabilities of the NASA STEM Engagement workforce.

NASA is committed to defining and implementing a portfolio of projects, activities, and products directed toward achieving the Agency's Strategy for STEM Engagement goals and objectives. Ultimately, the work dedicated to this strategy will contribute to achieving NASA's STEM Engagement vision to immerse students in NASA's work, attract students to STEM, and inspire the next generation to explore.

KEY ACHIEVEMENTS PLANNED IN FY 2023

NASA will devote increased investments in the Next Gen STEM project to further efforts in enabling K-12 student learning experiences and opportunities, and to conduct competitive opportunities for educators and educational institutions. Through efforts conducted within cross-cutting functions, NASA will advance its capacity to effectively reach students through efforts to develop and evolve a system to better access, navigate and use NASA STEM engagement resources and products. NASA will also further build connections with education ecosystems and networks and engage students by expanding the use of strategic partnerships and networks to magnify the impact of its efforts and investments. NASA will continue to enhance and evolve the STEM Gateway, to enable performance measurement and analytics, and will implement the next stage of the STEM engagement learning agenda, with completion of targeted studies to drive design and evolution of products and activities.

Specific achievements planned for the Space Grant, MUREP, EPSCoR, and Next Gen STEM projects are summarized in subsequent sections.

NASA SPACE GRANT

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**51.0**	**57.0**	**57.0**	**57.0**	**57.0**	**57.0**	**57.0**
Change from FY 2022 Budget Request			**0.0**				
Percent change from FY 2022 Budget Request			**0.0%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Kaytie Barkley, a mechanical engineering graduate student at South Dakota School of Mines & Technology, is shown here using an ultrasonic welder to fuse two pieces of plastic in a university lab. Barkley won a 2021 SDSGC Research Stipend followed by a 2021 NASA Space Technology Graduate Research Opportunities grant to undertake the research. The process she is studying could someday be used to build spacecraft.

Space Grant is a competitive grant opportunity that actively involves 52 consortia in 50 States, the District of Columbia, and the Commonwealth of Puerto Rico. Space Grant supports science, engineering, education, and research efforts for educators and students by leveraging the resource capabilities of over 1,000 affiliates from universities, colleges, industry, museums, science centers, and state and local agencies. Cooperative Agreements with each consortium align their work with the Nation’s science, technology, engineering, and mathematics (STEM) education priorities, NASA's missions, and the annual Agency performance goals.

Space Grant utilizes key NASA resources to provide students access to research and hands-on STEM learning experiences. These experiences may include working with high-altitude balloons, sounding rockets, aircraft, computer code, or small satellites. In order to maximize impact for these STEM investments, Space Grant leverages Agency resources in STEM education through strategic collaborations with NASA centers, subject matter experts, and mission directorates.

All activities conducted by the 52 consortia are in alignment with Agency goals, the Office of STEM Engagement (OSTEM) priorities, and the National Science and Technology Council's (NSTC) Committee on Science, Technology, Engineering, and Math Education (CoSTEM) priority areas. In terms of direct student support, Space Grant awards at the state level consist of scholarships, fellowships, and/or internships. The Consortia provide a broad array of projects in support of higher education, research infrastructure, as well as pre-college and informal education directly aligning with mission directorate priorities. Space Grant consortia also support flight project activities led by student teams. Some of those flight activities include:

- RockOn! Workshop - Colorado Space Grant Consortium;

NASA SPACE GRANT

- RockSat-C - Colorado Space Grant Consortium;
- First Nations Launch in collaboration with Minority University Research and Education Project (MUREP) - Wisconsin Space Grant Consortium; and
- High Altitude Student Platform (HASP) in collaboration with the Science Mission Directorate (SMD) - Louisiana Space Grant Consortium.

EXPLANATION OF MAJOR CHANGES IN FY 2023

No major programmatic changes are planned. However, with increased base award funding, each consortium will increase the number of student awards and other programming. NASA will look to expand opportunities to partner with mission directorates on awards that support mission priorities and align with Space Grant capabilities. Additionally, Space Grant will continue to monitor the Space Grant K-12 Inclusivity and Diversity in STEM (SG KIDS) awardees as they execute NASA-aligned hands-on activities that are geared towards historically underrepresented student populations.

ACHIEVEMENTS IN FY 2021

In FY 2021, Space Grant Consortia each received an opportunity to propose for $800,000 in Year 2 funds of the new four-year base award. These base awards will be active until FY 2024. These base awards implemented a significant programmatic change by dissolving the old Consortium classifications of Designated, Program Grant, and Capability Enhancement and providing level funding for all 52 Consortia. For this base award period, the Consortia proposed activities directly aligning with mission directorate needs and priorities. For the base award, the Consortia must apply at least 26 percent of their NASA funds toward direct student awards.

FY 2021 also saw continued progress of two Independent Program-Level Evaluation efforts competitively awarded to New Mexico State University and University of Alaska, Fairbanks. Both awards enable the Space Grant Consortia to interrogate timely and pertinent research questions about the overall efficacy of the Space Grant Program and how the States retain students in STEM. The two pilot awardees submitted evaluation plans that outline the work completed to date on their initial two-year award.

Space Grant also extended the promising activities of the Artemis Student Challenge awardees. These six awardees each received a portion of their funding from Space Grant, and other funding directly from mission directorates. This level of combined resources provides additional funding to the Consortia to conduct national-scale projects that expand the reach of the Artemis Campaign by making NASA's mission more accessible to students by directly leveraging the Consortia's 1000+ affiliate networks. These awards sought to interface with different student populations by focusing on three different themes. For Artemis Teaching and Resource Availability awards, the University of Alabama, Huntsville and the University of Illinois, Champaign-Urbana will provide foundational resources on specific aspects of the Artemis Program. For Artemis Core Technologies awards, the University of Colorado, Boulder and the University of Hawaii, Honolulu will provide hands-on learning activities of collegiate teams, utilizing small satellite platforms. Lastly, for Artemis Student Challenges awards, the University of California, San Diego, and University of Washington will each lead nationwide student challenges that will develop a Lunar/Martian lander, exploration, and habitation skills for university and community college students. This funded extension will allow awardees to implement a second year of their award to reach even more students nationwide.

NASA SPACE GRANT

Space Grant also provided additional opportunities for the Consortia to directly participate in other mission directorate projects or other OSTEM projects. Space Grant continued a partnership with the Space Technology Mission Directorate (STMD) to provide an expanded Breakthrough, Innovative, Game Changing Idea Challenge in FY 2020. The expansion allowed for larger awards to STMD selected teams from the Space Grant Consortia to design, build, and test a low-cost sample payload targeted for delivery to the lunar surface. The proposed payload should demonstrate technology systems design, develop, and demonstrate robotic systems with alternative rover locomotion modalities for use in off-world extreme lunar terrain applications.

Space Grant Awards in FY 2021		
Award Type	**Number of Awards**	**Funding Total**
Base Awards	52	$39,795,925
Space Grant Artemis Student Challenge Awards	6	$1,199,166
Special Topics	10	$678,870

COVID-19 directly impacted operations of every Consortium. Several universities faced staffing shortages and other COVID-related impacts affecting planned execution of their awards.

STEM Engagement:

In FY 2021, OSTEM transitioned from the Office of Education Performance Measurement (OEPM) system to a new NASA STEM Gateway (registration/application and data management system). This transition impacted the ability to collect performance data within historical data collection timelines. Therefore, all performance data reported should be considered preliminary as the verification and validation process has not been completed.

As a part of the overall Space Grant funding, Space Grant provided 4,001 significant student awards (e.g., internships, fellowships, engineering design challenges, student competitions, etc.) across all institutional categories and levels in FY 2021. These significant awards provided a total of approximately $14.6 million in direct financial support to higher education students.

Space Grant educator professional development participants included 16,835 in-service K-12 educators, informal educators, higher education faculty, preservice educators, and administrators. Additionally, 192,600 K-12 and higher education students participated in Space Grant STEM engagement opportunities.

Space Grant grantee and awardee institutions reported 1,934 peer-reviewed publications, technical papers, and presentations. Additionally, three patents and 11 technology transfers were granted.

WORK IN PROGRESS IN FY 2022

Space Grant consortia are currently implementing activities outlined in their four-year accepted proposals. In FY 2022, the Space Grant project will award a funding augmentation to each eligible Consortium, which provides the opportunity for the Consortia to propose raising their base award funding levels to

NASA SPACE GRANT

$860,000. Continued execution of the FY 2020 Independent Evaluation awards will provide interim evaluation plans to scale their pilot studies to encompass the entire program, and NASA will select a single awardee to implement the evaluation plan through a funded extension of two-years.

The Space Grant project will also solicit proposals seeking to increase middle and high school underserved and underrepresented students in hands-on, experiential learning activities on a regional scale where resources can be leveraged to address similar underserved student communities. This award will be called SG K-12 Inclusivity and Diversity in STEM (SG KIDS).

In addition to the above, the Space Grant project will continue productive partnerships with the mission directorates to more effectively engage Space Grant Consortia in mission priorities. A successful mission directorate partnership is the Space Grant collaboration with SMD to provide funding to support student teams and staff at Consortium offices for the Montana Space Grant Consortium, whose focus will be on the Eclipses of 2023 and 2024, and Central Washington University, whose focus will be on continuing the Northwest Earth Science Pathways Project. Additionally, Space Grant is partnering with the Aeronautics Research Mission Directorate (ARMD) to expand the number of awards from five to 10 for the ARMD University Student Research Challenge. Lastly, the Artemis Student Challenge awardees have made significant progress despite COVID-19 impacting their ability to recruit students, to have the students conduct the necessary research, and to access to the required facilities. All teams passed will conduct their final gate checks in time for Summer 2022 implementation and complete their remaining activity milestones. The Space Grant project continues to monitor the execution of all the awards especially considering continued impacts associated with the COVID-19 pandemic.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

The budget supports base awards for the 52 consortia to do the following:

- Provide hands-on learning experiences for U.S. graduate and undergraduate students to prepare them for the future workforce and/or academic careers;
- Conduct programs and projects that align with the NASA STEM engagement and mission directorate priorities, CoSTEM priority areas, and State-specific needs to build STEM pathways in higher education, research infrastructure, pre-college, and informal education;
- Amplify NASA's engagement around the 2023 and 2024 Eclipses;
- Continue the Program-Level Evaluation activity;
- Monitor the progress of the new K-12 awardees in expanding access to NASA-aligned activities in historically underrepresented student populations; and
- Expand opportunities for Consortia to contribute to NASA's mission through engaging with Aeronautics, thus expanding the portfolio beyond STEM research and activities related to human spaceflight.

NASA SPACE GRANT

Project Schedule

Date	Significant Event
Q2 FY 2022	Release of K-12 Notice of Funding Opportunity (NOFO)
Q3 FY 2022	Selections of K-12 awards
Q2 and Q3 FY 2022	Release of Year 3 base award funding
Q4 FY 2022	Down select of Independent Program-Level Evaluation Award
Q1 FY 2023	Fund Cohort 1 of ARMD and Space Grant University Student Research Challenges (USRC)
Q2 and Q3 FY 2022	Release of Year 4 base award funding
Q4 FY 2023	Year 1 Progress Review with K-12 awardees

Project Management & Commitments

The Space Grant Project Manager at NASA Headquarters provides management responsibility for day-to-day Space Grant operations. Civil servants at NASA centers actively engage with regional Space Grant Consortia, providing direction, oversight, and integration with center and mission directorate activities.

Acquisition Strategy

NASA solicits through competitive proposals from Space Grant 52 consortia in 50 States, District of Columbia, and the Commonwealth of Puerto Rico. Each Consortium program or project must align with the Administration priorities, NASA's Strategic Plan, and the NASA Strategy for STEM Engagement. All award selections undergo rigorous peer reviews by internal and external panels that evaluate technical merit, assess content, feasibility, and alignment to Agency STEM engagement, research, and technology goals. Awards are typically multi-year.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

NASA continues to use performance assessment and evaluation-driven processes to enhance the effectiveness of STEM engagement investments, executing a refined OSTEM learning agenda to understand the outcomes of its investments. Space Grant has continuously assessed its content and activities in pursuit of continuous improvement, in the context of the OSTEM learning agenda.

Space Grant will have an independent performance assessment review in the fourth quarter of FY 2024 to assess their accomplishments and strategies.

ESTABLISHED PROG TO STIMULATE COMP RSCH

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**26.0**	**26.0**	**26.0**	**26.0**	**26.0**	**26.0**	**26.0**
Change from FY 2022			**0.0**				
Percent change from FY 2022			**0.0%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

A student from the neuro-robotics lab at Wichita State University is shown here testing 3D virtual scenarios to evaluate human brain responses.

NASA's Established Program to Stimulate Competitive Research (EPSCoR) project provides cooperative agreements designed to establish partnerships between government, higher education, and industry to build stronger research and development capabilities in 28 eligible EPSCoR jurisdictions (states or regions). The project strives to improve a jurisdiction's research infrastructure to a level such that its research and development programs contribute to its economic development. EPSCoR supports competitively funded awards and provides research and technology development opportunities for research teams. NASA actively seeks to integrate the research conducted by EPSCoR jurisdictions with the scientific and technical priorities pursued by the Agency. EPSCoR has established a series of individual components to facilitate this work.

- EPSCoR Research Infrastructure Development (RID) Cooperative Agreement enables States to build and strengthen relationships with NASA researchers. Beginning in FY 2022, RID will have a five-year base period of performance with awards up to $200,000 per year, for a total of $1 million.
- EPSCoR Research Cooperative Agreement addresses topic-specific, high-priority NASA research and technology development needs. Awards are up to $750,000 for a three-year performance period with all funding provided at the beginning of the award.
- EPSCoR International Space Station (ISS) Flight Opportunity Cooperative Agreement utilizes the ISS as a microgravity platform or test bed for a space flight demonstration of the basic ground research.
- EPSCoR Suborbital Flight Opportunity Cooperative Agreement Pilot utilizes the STMD Suborbital Flight capability as a short-term microgravity platform or test bed for a suborbital flight demonstration (reusable rockets, balloons, or parabolic flight) of the basic ground research.

ESTABLISHED PROG TO STIMULATE COMP RSCH

- EPSCoR Rapid Response Research (R3) Cooperative Agreement is a collaborative effort between EPSCoR and the NASA Science Mission Directorate (SMD), NASA centers, commercial partners, and others, to provide a streamlined method to address high priority research issues important to NASA.
- EPSCoR uses the latest National Science Foundation (NSF) eligibility table to determine overall jurisdiction eligibility for NASA EPSCoR. The NSF eligibility table is available at: https://www.nsf.gov/od/oia/programs/epscor/Eligibility_Tables/FY2021_Eligibility.pdf

EXPLANATION OF MAJOR CHANGES IN FY 2023

The EPSCoR program partnered with the Space Technology Mission Directorate (STMD) to extend the NASA Suborbital Flight Opportunities (SFO) program to EPSCoR jurisdictions. The SFO facilitates rapid demonstration of promising technologies for space exploration, discovery, and the expansion of space commerce through suborbital testing with industry flight providers. EPSCoR will award researchers $200,000 to work with NASA for a three-year performance period with funding provided upfront and no cost-sharing requirement.

NASA/NSF EPSCoR Fellows Advancing in Science and Technology (FAST) Pilot is a joint pilot effort of NSF EPSCoR and NASA EPSCoR specifically focusing on Institutions of Higher Education (IHE), primarily serving underrepresented minorities, students with disabilities, women's colleges, and Primarily Undergraduate Institutions (PUI). NSF and NASA aim to recognize efforts to build research capacity and transform the career trajectories of early career investigators at these institutions and to further develop their individual research potential through extended collaborative research at selected NASA centers and at their home institutions.

ACHIEVEMENTS IN FY 2021

In FY 2021, NASA EPSCoR invested a total of $23,378,737 through awards via the components. Below are the amounts allocated to each element.

EPSCoR Awards in FY 2021 (Component Award Values)		
Element	**Awards**	**Total Amount**
EPSCoR Research Infrastructure Development (RID) continuation	28	$4,900,000
Research	16	$12,000,000
ISS Flight Opportunity	6	$700,000
Suborbital Flight Opportunity (SFO)	4	1,278,737
Rapid Response Research (R3)	43	$4,300,000
Total	**78**	**$23,378,737**

NASA EPSCoR funded academic research has provided benefits and increased competitive research capacity within targeted jurisdictions. The EPSCoR Stimuli document highlights EPSCoR funded

ESTABLISHED PROG TO STIMULATE COMP RSCH

research accomplishments within the eligible jurisdictions and is available here for 2017-2020: https://www.nasa.gov/stem/epscor/home/EPSCoR_Stimuli.html

The NASA EPSCoR project has grown over the years from one research solicitation per year and an infrastructure award every three years. The project has developed collaborative opportunities with the mission directorates to award Suborbital Flight Opportunities to conduct research and partnered with NSF in a pilot program titled the NASA/NSF Fellows Advancing in Science and Technology (FAST).

WORK IN PROGRESS IN FY 2022

EPSCoR will make new Research, R3, ISS, Suborbital, and FAST awards. Each funded proposal will establish research activities with the potential to make significant contributions to NASA's strategic research and technology development priorities while also contributing to the overall research infrastructure, science, and technology capabilities of higher education, and economic development within the EPSCoR jurisdiction.

Additionally, EPSCoR uses its collaboration with the nine NASA centers and JPL to provide workshops aimed at increasing each jurisdiction's knowledge of NASA's unique and innovative capabilities, resources, and facilities. Examples of this are proposal writing workshops, mission design classes, and bi-weekly research discussions between NASA and jurisdiction researchers.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

NASA EPSCoR will utilize the NASA Shared Services Center (NSSC) to fund year two of the 28 formula RID awards, 5-10 ISS Flight Opportunity awards, 4-6 Suborbital Flight Opportunity awards, 30-35 R3 awards, 15-18 Research awards, 5-10 FAST awards, support virtual research discussions, and support SMD/EPSCoR provided workshops. NASA EPSCoR research priorities are defined by the mission directorates, NASA centers, and the Jet Propulsion Laboratory (JPL). Each funded NASA EPSCoR proposal establishes research activities that will make significant contributions to the strategic research and technology development priorities of one or more of the mission directorate programs.

NASA EPSCoR utilizes the NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES) to conduct all research solicitations. For additional information on NSPIRES solicitations, please visit: http://nspires.nasaprs.com (select "Solicitations" and then "Open Solicitations" and type in keyword "EPSCoR"). NASA EPSCoR will provide an Appendix A to the Research solicitation. An Appendix A thru J to the R3 solicitation provides a summary of the Research priorities for each of the mission directorates and centers. These Appendices are provided in advance of the release of the solicitation to the jurisdictions so that they can plan their proposals and establish collaborations with NASA researchers.

ESTABLISHED PROG TO STIMULATE COMP RSCH

Project Plan

Date	Significant Event
Q1 and Q2 FY 2022	Release of Solicitations Research Cooperative Agreement Research Infrastructure Development (RID) EPSCoR Rapid Response Research (R3) ISS Flight Opportunity NASA/NSF Fellows Advancing in Science and Technology (FAST) Suborbital Flight Opportunities (SFO)
Q1 and Q2 FY 2022	Proposals Due and Review Process
Q3 & Q4 FY 2022	Selection and Awards: Research Cooperative Agreement Research Infrastructure Development (RID) EPSCoR Rapid Response Research (R3) ISS Flight Opportunity NASA/NSF Fellows Advancing in Science and Technology (FAST) Suborbital Flight Opportunities (SFO)

Project Management & Commitments

The NASA EPSCoR project manager is responsible for overall administrative duties of this national project. The project manager is located at Kennedy Space Center (KSC) and the new deputy project manager is located at Stennis Space Center (SSC). Management responsibility for day-to-day operations is provided by these two key positions. Contractor staff and representatives from each NASA mission directorate work closely with EPSCoR project management to ensure that current and future research requirements are in EPSCoR solicitations. The mission directorate representatives serve as the proposal selection committee, further ensuring that the selected work contributes to NASA priorities. Technical monitors from the NASA centers and Headquarters monitor and assess the progress of each award. They provide scientific guidance and technical advice as required throughout the year regarding the overall progress of the proposed effort and review all progress reports. Additional involvement may occur depending upon the nature of the collaboration already established or desired. This includes integrating the EPSCoR research into ongoing activities or research efforts and increasing the principal investigating team's awareness of other related or relevant research within NASA. Additionally, NASA is a member of the Federal EPSCoR Interagency Coordinating Committee (EICC) chaired by the NSF. The committee works to improve the leveraging of Federal EPSCoR investments. NASA EPSCoR continues to develop strategies to adhere to the guidance within the America COMPETES Act. The America COMPETES Act authorizes Federal investments in science and early-stage technology research and development (R&D). The original law was signed in 2007 and the latest reauthorization was signed on January 6, 2017 as Public Law 114-329. Among other provisions, the reauthorization affirmed the merit review process of EPSCoR research proposals and changed the name of EPSCoR to Established (instead of Experimental) Program to Stimulate Competitive Research.

ESTABLISHED PROG TO STIMULATE COMP RSCH

Acquisition Strategy

NASA solicits and awards EPSCoR Cooperative Agreements through a competition among institutions from EPSCoR States designated by the National Science Foundation (NSF). Each jurisdiction's proposal must align with the Administration's priorities and NASA's Strategic Plan. All award selections undergo rigorous peer reviews by internal and external panels that assess technical merit, content, feasibility, and alignment to Agency research and technology goals. Awards are typically multi-year.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

NASA EPSCoR continues to use performance assessment and evaluation-driven processes to enhance the effectiveness of the program. NASA EPSCoR utilizes reports from on-site subject matter experts from the mission directorates called technical monitors to evaluate the progress of EPSCoR funded research. The results from these evaluations and the jurisdiction's annual reports are published in a document titled Stimuli to demonstrate NASA EPSCoR results oriented reporting. Stimuli also summarizes the NASA EPSCoR technology development conducted by colleges and universities. This project benefits NASA's Earth science, aviation, and human and robotic deep space exploration programs, and supports NASA's other missions. Copies of the 2017-202 volumes can be viewed at: https://www.nasa.gov/stem/epscor/home/EPSCoR_Stimuli.html

MINORITY UNIVERSITY RESEARCH EDU PROGAM

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**38.0**	**48.0**	**48.1**	**48.1**	**48.1**	**48.1**	**48.1**
Change from FY 2022 Budget Request			**0.1**				
Percent change from FY 2022 Budget Request			**0.2%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

PR-SPRInT Principal Investigator, Dr. Eduardo Nicolau, works on an experiment with Perla Cruz-Tato (former NASA ASTAR Fellow). University of Puerto Rico, Rio Piedras astronauts' immune systems in space.

The Minority University Research and Education Project (MUREP) provides grants and cooperative agreements to the Nation's Historically Black Colleges and Universities, Hispanic Serving Institutions, Asian American and Native American Pacific Islander-Serving Institutions (AANAPISI), Tribal Colleges Universities, Alaska Native and Native Hawaiian Institutions (ANNH), Predominantly Black Institutions (PBI), and eligible community colleges. These minority-serving institutions (MSIs) play a vital role in educating students who may be underrepresented and underserved in STEM, including women and girls, veterans, and persons with disabilities. MUREP's investments in these MSIs are part of a comprehensive approach toward advancing equity for all, including people of color and others who have been historically underserved, marginalized, and underrepresented in STEM fields.

Participation in NASA projects and research has the potential benefit of both increasing numbers of students in STEM at all education levels and encouraging them to earn degrees in STEM fields that are critical to NASA and the Nation.

NASA's MUREP investments enhance the research, academic, and technology capabilities of MSIs through competitive, multi-year awards. Awards assist faculty and students in research and provide authentic STEM engagement related to NASA missions. These funded opportunities provide NASA-specific knowledge and skills to historically underrepresented and underserved students in STEM. MUREP investments also assist NASA in meeting the goal of a diverse future workforce through student participation in internships and fellowships at NASA centers.

MINORITY UNIVERSITY RESEARCH EDU PROGAM

EXPLANATION OF MAJOR CHANGES IN FY 2023

MUREP's research pillar will aim to assist in advancing the research and technological readiness levels of MSIs through not only consistent, competitive funding announcements, but also leveraging the resources of internal and external partners to position the project for greater scalability. MUREP will begin to work with Space Grant Affiliates at MSIs and develop relationships with STEM affinity organizations (i.e., American Indian Science and Engineering Society, National Society of Black Engineers, Society of Women Engineers with student chapters at MSIs). FY 2023 will see more concentration on MSI faculty and the role they play in student engagement. In addition, more robust data collection and reporting will provide insights and identify trends from the past three to five fiscal years related to MSI engagements, funding, student participations, courses created, and other Key Performance Indicators. This approach, coupled with project studies, will continue to hone the focus of MUREP's MSI efforts.

ACHIEVEMENTS IN FY 2021

In FY 2021, the Office of STEM Engagement (OSTEM) transitioned from the Office of Education Performance Measurement (OEPM) system to a new NASA STEM Gateway (registration/application and data management system). This transition impacted the ability to collect performance data within historical data collection timelines. Therefore, all performance data reported should be considered preliminary as the verification and validation process has not been completed.

Strengthening Minority Serving Institutions (MSI):

In FY 2021, MUREP provided engagement and oversight of 132 active cooperative agreement awards at MSIs across 29 states and territories.

MUREP provided 951 significant awards (e.g., internships, fellowships, engineering design challenges, student competitions) across all institutional categories and levels in FY 2021. These significant awards provided a total of approximately $3.5 million in direct financial support to higher education students at MSIs.

MUREP educator professional development participants included 33,028 in-service K-12 educators, informal educators, higher education faculty, preservice educators, and administrators. Additionally, 98,080 K-12 and higher education students participated in MUREP STEM engagement opportunities.

Innovations to Reach Target Populations during the COVID-19 Pandemic:

MUREP efforts shifted from in-person to virtual programming to support continued engagement of students, faculty, and strategic partners. A collaboration between the University of Texas at El Paso, a MUREP Aerospace Academy (MAA) awardee, and Gadsden Independent School District in New Mexico demonstrates an innovative approach to virtual engagement of underserved and underrepresented communities during the pandemic. The plan to retrofit vehicles to host internet access points allowed STEM engagement opportunities for surrounding remote communities. Initiatives such as this highlight the importance of partnerships within a within a STEM ecosystem that expand the reach of engagement opportunities with students, educators, and families.

MINORITY UNIVERSITY RESEARCH EDU PROGAM

Leveraging Technology to Drive Participation:

The MSI Exchange is a searchable database that helps those looking for diverse academic collaborators. The MSI Exchange is a curated collection of MSI profiles that include institutions' STEM offerings and capabilities. As an online matchmaking tool, the MSI Exchange aids Federal researchers, industry, and principal investigators seeking diverse partners for mission-focused research through Cooperative Agreements, Space Acts Agreements, grants, and other Federal contracts. The MSI Exchange was piloted in FY 2019 for use through a technology enterprise team at NASA Headquarters and launched in FY 2020. Since then, it has scaled to become a resource for internal and external stakeholders through the addition of digital badges, professional development that promotes MSI competitiveness, and by providing an official NASA MSI List (see: https://www.nasa.gov/sites/default/files/atoms/files/edu_nasa_msi_list_aug_2021.pdf), used to verify an institution's MSI status to determine eligibility for NASA solicitations. Future opportunities to scale the MSI Exchange offerings include rolling out a strategy that identifies the requirements of each mission directorate and matches them with the capabilities of MSIs. For more information, go to: https://msiexchange.nasa.gov/

The MUREP Institutional Research Opportunity (MIRO) aims to promote literacy in STEM at MSIs and to enhance the sustainable capabilities of institutions to perform research and education aligned to NASA's mission. Twenty of these research awards were under cooperative agreement management going into FY 2021 and resulted in 492 peer-reviewed publications, technical papers, and presentations. Additionally, eight patents and one technology transfer were granted.

MUREP has instituted the use of planning grants as a method to attract and prepare MSIs who desire to compete for larger funding opportunities. The planning grants have allowed MUREP to better understand the research capabilities of those MSIs who have traditionally not submitted proposals and to leverage relationships to build a more robust MSI pipeline. These planning grants yielded 32 new awards to 24 MSIs.

WORK IN PROGRESS IN FY 2022

MUREP will support multiple award selections to MSIs under the newly released FY 2022 Engagement Opportunities in NASA STEM (EONS) solicitation. By continuing to align much of its funding opportunities to mission directorate research focus areas, MUREP not only adds value to accomplishing the Agency's mission, but through its collaboration and partnering relationships with other Federal Agencies, academic and industry leaders, it also develops deeper connections and engagement with MSIs.

MUREP's American Indian and Alaska Native STEM Engagement (MAIANSE) seeks to increase American Indian and Alaska Native engagement in science, technology, engineering, and mathematics (STEM) through authentic and unique NASA experiences. By collaborating with multiple indigenous affinity groups, like the American Indian Science and Engineering Society (AISES) and the American Indian Higher Education Consortium (AIHEC), and creating student engagement options with the Choctaw Nation of Oklahoma via NASA Astro Camp, Tribal Colleges and Universities can learn diverse ways to honor traditional customs and practices, while actively participating in OSTEM challenges, competitions, and research offerings.

MUREP will also focus on developing a Student Engagement Strategy that balances a portfolio of activities with a diversity of student participants and MSI types toward enhancing STEM degree

MINORITY UNIVERSITY RESEARCH EDU PROGAM

attainment for underrepresented and underserved students in NASA-related STEM majors by providing opportunities to engage in mission-driven research and technology development efforts. FY 2022 will advance efforts to fund High School bridge programs with students likely to matriculate at MSIs. These opportunities will drive awareness for these students. While student competitions and challenges will continue to be important, there will be greater emphasis on creating synergy amongst the different activities and finding ways to introduce greater groups of students to the entire portfolio for multiple touch points into OSTEM programming.

Due to COVID-19 restrictions, the expansion of virtual offerings for STEM Engagement efforts, as well as center-based research experience, was necessary to meet the needs of MSI students and faculty.

MUREP plans to provide new internship and fellowship opportunities so that students can work with mentors and other interns to grow in their STEM awareness and knowledge while moving along a path toward STEM degree attainment during the sessions. MUREP Innovative Technology Transfer Idea Challenge (MITTIC) and NASA Community College Aerospace Scholars (NCAS) both made excellent transitions of their team-based competitions to fully virtual execution and still found creative avenues to broaden student participation, expand reach in recruitment, and provide incentives to sustain the engagement throughout the lifecycle of the activities. Over 35 states were represented in the student competitions.

MUREP has leveraged key partnerships to drive its strategic priorities and increase long-term competitiveness at MSIs including: 1) supporting relationships through collaboration with the Aeronautics Research Mission Directorate (ARMD) on the MUREP High-Volume Manufacturing activity; 2) formalizing internal NASA relationships via the NASA Technology Infusion Road Tour events in partnership with the Offices of Small Business Programs, Procurement, and SBIR/STTR (over 100 MSIs participated in these events collectively); and 3) leveraging external partnerships like the work of broadening participation in engineering with the NSF through a formal MOU and solicitation. An additional collaboration was formed with the Department of Education/Upward Bound Program. MUREP's desire to support bridge efforts at HBCUs and PBIs is being realized through this effort.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

Building upon work co-created by MUREP for American Indian and Alaska Native STEM Engagement (MAIANSE) and other indigenous collaborators, the MAIANSE Connect competitive solicitation will select and award funding to ANNH serving Institutions, Tribal Colleges and Universities, and other higher education institutions to foster the connections of scientific research and the integration of indigenous practices. The new awards / projects will begin to be implemented across the country with new research and student engagement activities.

The implementation of a HBCU-focused sub-project would be specifically designed to address deficits in STEM research, faculty development and student success. Funding will be provided to initiate, advance, implement, and broaden efforts developed by the Nation's HBCUs. The overall aim will be to support competitiveness and sustainability post awards.

Further expansion of research efforts that fund MSIs with necessary resources are critical to build capacity and develop Centers of Excellence that transcend the original awards provided by NASA. These

MINORITY UNIVERSITY RESEARCH EDU PROGAM

interdisciplinary efforts are cross-cutting and align directly with mission directorate priorities. The new MUREP Institutional Research Opportunity (MIRO) solicitation will be released in FY 2023.

An opportunity is available to engage Women's Colleges & Universities beginning the 1st Quarter of FY 2023, looking into the disparities faced by women in STEM disciplines as well as the efforts initiated in these women only institutions. Focused research was conducted in FY 2021 - 2022 to look at feasibility and viability of this pilot activity.

Project Schedule

EONS is an omnibus announcement that includes a range of NASA STEM Engagement opportunities for basic and applied science and technology research and education. In response to feedback from the MSI community, several improvements to EONS were made in FY 2021, including: 1) establishing November as the set month of release for each updated version of EONS; 2) releasing an annual schedule of NRAs projected to be released under EONS; and 3) proposal writing webinars and workshops to aid MSIs in preparing successful proposals.

The table below includes significant FY 2022 milestones.

Date	Significant Event
Q1 FY 2022	Open EONS Omnibus Solicitation; Release MUREP Pre-College Summer Institute (PSI) appendix; Release MAIANSE Connect appendix
Q2 FY 2022	MUREP Aerospace Academy (revised) appendix Release
Q3 FY 2022	MUREP STTR Solicitation Release
Q4 FY 2022	Research and Capacity Building appendix Release

Project Management & Commitments

The MUREP project manager is located at NASA Headquarters and provides management and oversight for overall activity operations. NASA centers manage significant investments in project activity elements. MUREP activities map strategically to four investment pillars: Research Infrastructure and Capacity Building, Curriculum Development and Service Provider Resources, Student Engagement and Partnerships & Sustainability.

Acquisition Strategy

NASA MUREP awards cooperative agreements, grants, and contracts (if applicable) through full and open competition.

MAJOR CONTRACTS/AWARDS

None.

MINORITY UNIVERSITY RESEARCH EDU PROGAM

Independent Reviews or Evaluation

All MUREP activities document performance through either external evaluations or internal reviews.

In FY 2021, MUREP concluded a two-phased study of the portfolio. In Phase 1, a critical examination of selected activities was completed to develop a more evidence-based understanding of: 1) the efficiency and effectiveness of management operations; 2) alignment to OSTEM and MUREP priorities, goals, and objectives; 3) promising practices; and 4) the role of partnerships and sustainability efforts. In Phase 2, the study addressed Student Engagement & Partnerships. Emphasis was given to the overall solicitation process; attracting and recruiting of students from groups historically underrepresented and underserved in STEM for activities, events, challenges, and competitions; and to what extent MUREP's activities increased the overall competitiveness of its Awardees. With a utilization-focused analysis, the findings of the study focused on overall usefulness to MUREP across the two phases, review of extant research related to the constructs examined, and feedback from Expert Review Panel (ERP) meetings supported the development of a MUREP comprehensive program-level theory of change and logic model. Overall findings and recommendations were used to prioritize MUREP investments; share promising practices within and across activities; influence activity design; improve sustainability; and lower barriers to entry for evidence-based decision-making.

NEXT GEN STEM

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**12.0**	**16.0**	**19.1**	**22.1**	**25.2**	**28.3**	**31.5**
Change from FY 2022 Budget Request			**3.1**				
Percent change from FY 2022 Budget Request			**19.4%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Key Next Gen STEM initiatives for integrating NASA STEM Engagement offerings for delivery to pre-college students and educators.

Next Gen STEM focuses on building a future STEM workforce, with an emphasis on learning opportunities for students in grades K-12, by infusing the excitement of NASA missions and programs into an integrated portfolio of educational products, experiences, challenges, and competitive awards. Next Gen STEM reaches students in school, in after school programs, in informal education institutions (e.g., museums and science centers), and at home. Next Gen STEM seeks to broaden student participation in STEM by ensuring the greatest accessibility to NASA STEM opportunities, challenges, experiences, and educator support to effectively contribute to building a diverse and inclusive STEM workforce for the future of the Nation.

Next Gen STEM includes a comprehensive program in support of Informal Education Institutions (IEIs) through both its Museum and Informal Education (MIE) Alliance (formerly Museum Alliance) community of practice and its competitive awards program, Teams Engaging Affiliated Museums, and Informal Institutions (TEAM II). TEAM II provides a competitive awards program for science centers, museums, planetariums, NASA visitor centers, and other IEIs.

EXPLANATION OF MAJOR CHANGES IN FY 2023

The NASA budget provides a $3 million increase for Next Gen STEM (relative to the FY 2022 request) to continue to grow the project's educational offerings and to serve as the integration point and service provider for K-12 initiatives across the Agency. Next Gen STEM has a primary goal of lowering barriers

NEXT GEN STEM

to participation experienced by students and educators, especially those in communities historically underserved or underrepresented in STEM.

Two efforts piloted and launched in FY 2022 will be expanded in FY 2023. NASA Connecting our NASA Network of Educators Collaborating in STEM (CONNECTS) is an active, interactive community of practice serving both formal and informal educators, which allows K-12 instructors to interact with NASA experts and each other, to easily and effectively incorporate NASA content in their programs and classrooms. NASA Sparking Participation in Authentic Real-world eXperiences (SPARX) challenges and competitions deliver hands-on experiences for students of all educational levels and build STEM identity through a continuum of offerings that meets students where they are in their STEM learning journey.

In FY 2023, increased project funding allows increased awards to IEIs through TEAM II. This will include additional awards ranging from $750,000 to $1 million and smaller Community Anchor awards. Community Anchor awardees receive $25,000 to help them establish themselves as new or emerging local NASA STEM informal education community resources and to reach into communities underserved and underrepresented in STEM with the most current and authentic NASA content and experiences. The Community Anchor cohort was established in FY 2022 as a special subcommunity of the MIE Alliance within NASA CONNECTS and this cohort will expand in FY 2023 through additional Community Anchor awardee selections and advances in effectiveness, based on member feedback.

ACHIEVEMENTS IN FY 2021

In FY 2021, Next Gen STEM undertook a deep examination of its goals and objectives, project structure, and project portfolio. While providing five major student challenges and developing numerous new educator resources and delivering weekly STEM role model engagements, Next Gen STEM designed and piloted a new educator community of practice (NASA CONNECTS). NGS also created a new structure of student challenges and competitions, NASA SPARX, for pilot in FY 2022. SPARX is designed to increase student participation and lower barriers to entry through providing a research-based continuum of offerings that span students' depth of knowledge in STEM. Educational products were reimagined to be more accessible and usable by all types of educators, while retaining academic rigor and alignment to national standards. Next Gen STEM continues to flourish in the face of the global pandemic, delivering its offerings virtually while addressing inequities in digital access through strategic partnering. A few examples of FY 2021 achievements include:

Next Gen STEM's "STEM on Station" activity saw a large increase in the number of educational downlinks, due to the addition of the Space-X Dragon astronauts of the Crew-1 and Crew-2 missions, with 27 educational downlinks accomplished in FY 2021, including the first-ever downlink event for blind, deaf, visually impaired, and hearing-impaired students. Downlink events are unique opportunities where groups of students ask questions of astronauts working on the International Space Station (ISS), as part of a larger educational experience designed for the participants. Over 23,000 students were involved in these events in FY 2021 along with 6,000 educators. STEM on Station also reached 1.1 million cumulative downloads of its astronaut STEM principal demonstrations, "STEMonstrations."

TEAM II awarded three additional proposals in FY 2021 for a total of $3 million from the FY 2019 solicitation. In addition, the seven rapid response awards selected in late FY 2020 were executed to reach students still experiencing virtual learning due to the pandemic. The FY 2021 TEAM II awardees are listed in the table below. FY 2021 also saw the release of a new TEAM II solicitation with both the large

NEXT GEN STEM

awards and a new Community Anchor award category to help newer and smaller informal education institutions utilize NASA content and prepare for larger award opportunities. Selection of these awardees is scheduled for first quarter of FY 2022.

TEAM II Awardees	Project
Space Science Institute, Boulder, CO - $998,198	From Our Town to the Moon, Mars and Beyond
The Science Center, Ithaca, NY - $998,433	Explore Science, Destination Moon
The Franklin Institute, Philadelphia, PA - $999,807	Mission to Mars: Boosting Community Engagement with NASA Resources

The NASA STEM Stars initiative, which was created in FY 2020 in response to the need for virtual engagement of students, came into its own in FY 2021. These live virtual events allow students to meet and ask questions of a variety of NASA STEM professionals from diverse backgrounds, whose personal stories and current work spark student interest in STEM and help them envision themselves in STEM careers. These weekly episodes, and monthly episodes in Spanish, garnered approximately 30,000 live and asynchronous views in FY 2021.

The Next Gen STEM project developed and released five extensive new educator guides and a K-4 storybook, delivering many new classroom activities aligned to national Next Generation Science Standards (NGSS) and tied to the exciting missions and research of NASA. In addition, a special curation of Science Mission Directorate (SMD) resources was produced by Next Gen STEM to build excitement around astrophysics and the launch of the James Webb Space Telescope. Also, a Next Gen STEM curation was created and employed in the extensive Mars Student Countdown program for the Mars Perseverance Rover's landing on Mars in February 2021.

The Artemis Moon Pod Essay Contest was developed and implemented by the Next Gen STEM project in collaboration with the Exploration Systems Development Mission Directorate, with over 14,000 entries, 155 semifinalists, and three winners (from three grade divisions). Finalists participated in interview sessions with the contest judges and prizes were distributed for winners, finalists, and semifinalists.

In FY 2021, the Office of STEM Engagement (OSTEM) transitioned from the Office of Education Performance Measurement (OEPM) system to a new NASA STEM Gateway (registration/application and data management system). This transition impacted the ability to collect performance data within historical data collection timelines. Therefore, all performance data reported should be considered preliminary as the verification and validation process has not been completed.

Next Gen STEM educator professional development participants included over 30,000 in-service K-12 educators, informal educators, preservice educators, and administrators. Additionally, over 1.6 million K-12 students participated in Next Gen STEM engagement opportunities.

WORK IN PROGRESS IN FY 2022

In FY 2022, Next Gen STEM is launching exciting new initiatives like the NASA CONNECTS educator community of practice and the NASA SPARX challenge and competition pilot. Also, through its

NEXT GEN STEM

revamped mission focus areas: Earth, Moon, Aeronaut-X, and Solar System and Beyond, the project will continue to create standards-aligned education resources and impactful virtual and in-person student experiences and educator training. Some notable efforts currently in progress are:

The SPARX challenges pilot is underway with over 9,500 students participating, many from underserved and underrepresented populations. Six partner organizations have enabled the participation of this record number of students and will provide feedback and formal evaluation on the pilot to inform improvements for the planned public launch of SPARX in FY 2023.

The NASA CONNECTS educator community of practice has concluded two pilot sessions with educators and is currently executing a "beta test" with an expanded group of teachers before formal public launch later in the year. Development of the online environment and tools continues with MIE Alliance to soon migrate to the new platform to deliver enhanced capabilities for all users.

The excitement of the ISS and astronauts launched from the U.S. with the Commercial Crew Program vehicles will continue to be translated into authentic student learning experiences and standards-aligned educational resources through the ISS Downlinks, “STEMonstrations”, and Commercial Crew initiatives of the Earth focus area. The advances of scientific missions in Earth orbit will also be used to bring the importance of Earth and climate science to K-12 students.

New educational products and experiences and curations of existing NASA resources are centered on NASA’s key FY 2022 launches, Artemis I and the James Webb Space Telescope, to spark student interest and learning and help them see themselves in future NASA missions and in the Nation’s future STEM workforce.

Evolution of virtual engagements with students, like NASA STEM Stars, are underway to increase reach and impact. In addition, a training and support initiative is being designed to better enable NASA STEM professionals to make a positive impact on K-12 students in formal and informal and virtual and in-person engagements.

The Next Gen STEM project will also enhance its portfolio of competitive opportunities for informal educational institutions through the selection of new TEAM II awardees and the inaugural TEAM II Community Anchor awardees, and initiation of their projects and the Community Anchor cohort activities.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

In FY 2023, several key efforts begun in FY 2022 will be evolved, enhanced, and extended, informed by participant feedback and formal evaluation. These efforts will be detailed below. In addition, Next Gen STEM will take concrete steps in FY 2023 to, as part of the larger NASA K-12 STEM Engagement community, develop relationships with the States’ STEM education organizations to better understand educator needs and address them through NASA STEM Engagement offerings. Additionally, strategies to meet educator needs on a larger scale will be investigated through partnerships with other Federal agencies.

The NASA SPARX challenges will expand offerings to include the breadth of major NASA mission and project themes across four depth-of-knowledge levels and all will be publicly available and specifically marketed to broaden student participation. In addition, the NASA CONNECTS educator community of

NEXT GEN STEM

practice will expand its membership and offerings of NASA resources, expand its capability to support membership needs and look to partner with other Federal agencies to feature a broader array of STEM resources for increased beneficiary effectiveness. Also, NASA CONNECTS will become a cornerstone for increased efforts to partner across the States' STEM education organizations to better understand, and serve, the needs of formal educators. Finally, FY 2023 will mark the inaugural year of an Agency-wide STEM role model training. This support and assignment program is designed to maximize the effectiveness of NASA STEM professionals to spark and sustain student interest and efficacy in STEM learning. This program seeks to ensure that students have access to effective role models from NASA's workforce that look like them and that are trained to conduct grade-appropriate and culturally appropriate engagements for K-12 students across the Nation.

In FY 2023, Next Gen STEM will continue to provide products aligned to four mission focus areas: Aeronautics, Earth, Moon, and Solar System and Beyond. These four mission-driven focus areas will support content development and delivery, student experiences and educator support within their exploration areas and will seamlessly support multiple mission directorates, while integrating with each other to ensure consistency. External beneficiaries will find navigating offerings from these four focus areas intuitive since the educational content will closely align to the Agency's public communication themes and will be curated and marketed in ways that are relevant to the educator, with NASA CONNECTS as a key enabling tool in this endeavor.

Additional full TEAM II awards and smaller Community Anchor awards for informal education institutions will be awarded in FY 2023. These awards will continue to extend partnership with community organizations across the Nation and extend the reach and efficacy of Next Gen STEM and NASA STEM Engagement to inspire, engage, and educate pre-college students.

Project Schedule

As described in previous sections, FY 2022 will be a pivotal year, with many new and improved products and offerings for K-12 students, informal and formal educators, and IEIs.

Date	Significant Event
Q1 FY 2022	Selection of TEAM II Standard and Community Anchor Awards
Q3 FY 2022	Release of a FY 2022 TEAM II Community Anchors-only Solicitation
Q4 FY 2022	Kick off 2023-2024 school year with new content and announcement of offerings for SPARX challenges and competitions
Q1 FY 2023	Awarding of additional TEAM II Standard and new Community Anchor Awards
Q1 FY 2023	Public launch of NASA SPARX challenges and competitions
Q2 FY 2023	Recruitment and selection of NASA STEM professionals for K-12 STEM Engagement training program
Q2 FY 2023	Launch STEM Subject Matter Expert training program for effective STEM engagement with students
Q3 FY 2023	Release of TEAM II awards solicitation

NEXT GEN STEM

Date	Significant Event
Q3 FY 2023	Conclusion of NASA SPARX student challenges and competition with culminating events
Q3 FY 2023	Release summer camp content and plans for 2022-2023 school year

Project Management & Commitments

The Next Gen STEM project manager is physically located at NASA Marshall Space Flight Center and reports to NASA Headquarters. The TEAM II/MIE Alliance activity manager is located at NASA Headquarters. The remainder of the Next Gen STEM activity leads and all supporting personnel for project efforts are located at various NASA field centers. The current Next Gen STEM elements are as follows:

- Earth (Includes STEM on Station, Commercial Crew and Earth Science groups);
- Moon;
- Aeronaut-X;
- Solar System and Beyond;
- Competitive Awards - TEAM II;
- Community of Practice; and
- NASA CONNECTS – Contains Formal and Informal (MIE Alliance) Subgroups.

Acquisition Strategy

Consistent with existing NASA practices, NASA uses cooperative agreements, grants, and contracts through full and open competitions. All Next Gen STEM award selections undergo rigorous peer reviews by internal/external experts, usually including panel reviews, that evaluate proposals technical merit, feasibility, and alignment to Agency STEM Engagement goals and objectives.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

NASA continues to use performance assessments and evaluation-driven processes to enhance the effectiveness of STEM engagement investments, executing a refined OSTEM learning agenda to understand the outcomes of its investments. Since its inception in 2018, Next Gen STEM has continuously assessed its contents and activities in pursuit of improvements to the OSTEM learning agenda.

In FY 2020, a study was conducted to examine the Sparking STEM Interest Expert Review Panel recommendations about sparking and sustaining student interest in STEM. The panel was convened in response to the NASA Advisory Council's recommendation that "The Office of STEM Engagement

NEXT GEN STEM

should create a deep and comprehensive document that describes what we know about sparking student interest, STEM engagement, and motivation."

The Sparking STEM Interest Study recommended strategies for Next Gen STEM to effectively partner with external organization to create networks that maximize reach and impact of STEM engagement opportunities and for Next Gen STEM to deliver evidence-based transdisciplinary learning opportunities. The study was informed by convening focus groups of educators and institutional representatives and by conducting a literature review and benchmarking study. The findings and recommendations from this study were used to support the design of the FY 2021 Next Gen STEM outcome evaluation, which assessed the project's implementation against intended outcomes. This FY 2021 study also assessed how NASA could develop data collection, analysis, and reporting mechanisms to better assess the extent to which Next Gen STEM activities spark student interest in STEM.

Overall, findings from the FY 2021 Next Gen STEM pilot outcome study indicated that participants experienced positive change as reflected by students' self-reported gains in STEM career interest, STEM career knowledge, critical thinking, perseverance, relationships with adults, fascination in science, and competency beliefs in STEM. Additionally, the study identified a need for the development of a data collection approach for web-based platform delivery and recommended creating a custom instrument aligned to NASA intended outcomes.

Based upon findings and recommendations from the Next Gen STEM pilot outcome study and an internal K-12 Strategic Assessment, NASA plans to develop and validate education tools (e.g., surveys, assessments) for future outcome assessments of K-12 programming and to conduct a K-12 Stakeholder Needs Assessment and Gap Analysis in FY 2022. This study will 1) assess the extent to which stakeholders are using NASA STEM Engagement K-12 activities; 2) determine strengths and potential areas of improvement for NASA STEM Engagement K-12 activities; 3) investigate challenges that stakeholders experience when using NASA STEM Engagement K-12 activities; and 4) determine stakeholders' suggestions for future NASA STEM Engagement K-12 activities.

SAFETY, SECURITY, AND MISSION SERVICES

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Mission Services & Capabilities	1,918.3	2,028.8	**2,154.4**	2,197.5	2,241.5	2,286.3	2,332.0
Engineering, Safety, & Operations	1,018.2	1,020.4	**1,054.3**	1,075.4	1,096.9	1,118.9	1,141.3
Total Budget	**2,936.5**	**3,049.2**	**3,208.7**	**3,272.9**	**3,338.4**	**3,405.2**	**3,473.3**

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

SAFETY, SECURITY, AND MISSION SERVICES

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Mission Services & Capabilities	1,918.3	2,028.8	**2,154.4**	2,197.5	2,241.5	2,286.3	2,332.0
Engineering, Safety, & Operations	1,018.2	1,020.4	**1,054.3**	1,075.4	1,096.9	1,118.9	1,141.3
Total Budget	**2,936.5**	**3,049.2**	**3,208.7**	**3,272.9**	**3,338.4**	**3,405.2**	**3,473.3**
Change from FY 2022 Budget Request			**159.5**				
Percent change from FY 2022 Budget Request			**5.2%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The first joint integrated SLS launch countdown simulation (shown here) involved engineers from Centers in Texas, Alabama, and Florida, moving NASA's Artemis Campaign forward. This milestone was supported by foundational IT, business, and facility services.

Safety, Security, and Mission Services (SSMS) enable NASA's missions by providing foundational support capabilities to meet NASA's evolving mission requirements with efficiency and effectiveness.

SSMS funding provides resources for essential business and technical functions across 9 NASA centers and Headquarters (HQ). NASA manages operations with independent oversight to ensure the health and safety of NASA employees and the public. SSMS programs provide services and capabilities that ensure NASA has the technical skills, physical and information technology (IT) assets, financial resources, and top talent to be successful, safe, and reliable.

Mission Support Priorities

Goal 4 of the NASA Strategic Plan 2022 directs NASA's mission support functions to enhance capabilities and operations to catalyze current and future mission success through three key objectives: (1) attract and develop a talented and diverse workforce; (2) transform mission support capabilities for the next era of aerospace; and (3) build the next generation of explorers. Functions and capabilities that align to these three priorities comprise the foundational business that supports NASA activities, including the Agency's mission goals.

Mission support's strategic approach ensures that critical services are mission ready as requirements evolve and foundational services are keeping pace with cybersecurity, industry standards and Agency needs. The following mission support management goals and objectives direct funding to the critical capabilities needed for mission success by staying focused on mission needs, center conditions, and transformational opportunities:

- Service Delivery: provide expert technical and professional support services and capabilities to NASA's missions.

  - Manage programs to ensure the health, safety, and security of NASA people, property, and the public while enabling mission success through technical excellence;
  - Maintain and modernize NASA assets, including physical and IT infrastructures, to meet mission needs;
  - Protect and securely share NASA's critical data, information, and knowledge to enable mission success; and
  - Continuously improve NASA employee talent management to remain competitive for top talent and provide constant professional growth to the workforce.

- Customer Experience: create and maintain a premium customer experience for NASA's mission directorates and centers.
  - Ensure ongoing engagement with customers to understand, integrate, and prioritize evolving customer needs and service requirements;
  - Promote diversity, inclusion, and engagement in the workforce and work environment reflective of NASA's core values; and
  - Target, anticipate, and exceed customer needs using robust data analytics.

- Agility and Innovation: create an environment of continuous transformation and stewardship resulting in more efficient and effective operations.
  - Prioritize investment in projects that enhance, transform, and reduce costs of service delivery;
  - Utilize data-driven processes for prioritizing and integrating work, risk, resources, and decision making;
  - Streamline services and shift from low-value to high-value work by eliminating unnecessary work, optimizing critical work, and automating wherever possible; and
  - Create workspaces enabled with 21st century technology, virtual environments, and solutions that support distributed work teams and flexible work environments.

Mission support functions and capabilities comprise the foundational business areas that support NASA activities, including the other three goals of Agency strategy. Industry and academic collaborations, modernized labs and equipment, a highly talented and diverse workforce, and IT capabilities are paramount to expanding scientific discoveries (Goal 1). Launch and testing facilities, mission assurance and safety oversight, center infrastructure, protective services, and an empowered engineering workforce enables the extension of human presence deeper into space (Goal 2). Communicating NASA's discoveries and data, forming legal and strategic bonds with industry and international space collaborators, securing national assets, and providing technical guidance for safety and health help to catalyze sector growth (Goal 3). To achieve this level of service, SSMS must prioritize critical support, optimize operations, and mature enterprise capabilities.

Mission enabling capabilities provide support needed to successfully and safely implement and complete requisite missions. The following are several examples of services funded under the SSMS account:

- Management of test facilities, laboratories, chambers, and other mission enabling capabilities required to conduct research, development, and engineering for Agency mission objectives;
- Development of engineering and safety and mission assurance capabilities that support independent technical authorities and technical activities;
- Modern IT services with secure digital capabilities and data management that support NASA's missions and workforce;
- Human capital, financial management, procurement, legal counsel, small business programs, occupational health and safety, and equal employment opportunity and diversity services providing

strategic and operational planning and management to ensure resources are available when needed; and
- Administration of international and interagency relations, legislative and intergovernmental affairs, and strategic communications to facilitate communications with a broad range of internal and external communities.

Balancing SSMS and CECR

NASA's mission support portfolio is divided between two accounts: Safety, Security, and Mission Services (SSMS); and Construction and Environmental Compliance and Restoration (CECR). The Mission Support Directorate (MSD) utilizes both accounts to maintain NASA's critical infrastructure. MSD must balance spending on the maintenance of assets and infrastructure, repairs and renewal of failing assets, and the replacement and demolition of obsolete assets. Required maintenance activities drive SSMS spending decisions, while repairs, renewals (including new construction), and associated demolition drive CECR spending.

Much of NASA's infrastructure dates back to Apollo-era space exploration. Maintenance activities funded by SSMS are necessary to prevent costly delays to missions and risks to health and safety. Meanwhile, failures require immediate repairs and account for an increasing share of the maintenance budget. These activities are vital to support evolving mission requirements. The increasing activities in commercial space development and exploration strain the Nation's degrading infrastructure. Investments in NASA's foundation infrastructure and unique capabilities will position the Nation to continue supporting a national space economy for the next era of space exploration. With current resources, MSD takes an Agency-wide approach to make difficult trade-off decisions that ensure critical capabilities and assets are mission-ready, while also investing in the long-term asset health, sustainability, and footprint reductions that ensure NASA's future mission success.

EXPLANATION OF MAJOR CHANGES IN FY 2023

To align with NASA's priorities, SSMS services and content will be increased in the following areas as described in the program sections below: IT Infrastructure and Cybersecurity (see IT); Agency-Wide Security (see MES); Health & Safety (see ATA); Diversity, Equity, Inclusion, and Accessibility [DEIA] (see MES); and Physical Assets and Infrastructure Maintenance (see I&TC).

ACHIEVEMENTS IN FY 2021

The following achievements are major milestones and highlights. More robust lists of accomplishments are available in the program sections.

- Provided secure, accessible, and leading-edge IT infrastructure, services, applications, and platforms:
  - Improved IT data accessibility for multiple stakeholders. Examples include meeting intensive data storage needs of the Artemis Campaign by moving to a common cloud platform and minimizing local infrastructure cost by migrating to Agency-wide cloud solutions;
  - Enhanced IT capabilities through accelerated adoption of workplace and collaboration tools, such as Microsoft Teams. These capabilities and numerous enhancements during FY 2021 also served as a permanent enhancement of NASA's enterprise digital capabilities;

- Responded to COVID-19 telework conditions, including the dramatic increase in use of Agency's Virtual Private Network (VPN), as well as provided on-site 24/7 communications support for critical Agency spacecraft operations; and
- Continued to operate NASA's Communications (NASCOM) Mission Backbone (NMB); provided critical support to numerous critical launches and events, including Commercial Crew, ISS resupply, Soyuz, LUCY, and ISS EVAs.

- Provided foundational business services to enable mission activities:
  - Developed DEIA performance requirements for all executives, managers, and supervisors;
  - Shifted more work to cloud storage, leveraging collaboration and virtual tools, and enhanced work with automation capabilities;
  - Broadcast mission and NASA content through modern, digital, and social media platforms; and
  - Supported a dynamic legal framework to support the mission related Space Act Agreements to foster growth in the space industry, including commercial service utilization for NASA.

- Maintained and enhanced NASA's physical asset portfolio, including facilities, roads, and utilities, and commitment to environmental stewardship:
  - Installed condition-based maintenance (CBM) sensors and capabilities across all centers, resulting in $27 million worth of cost avoidance;
  - Refurbished JSC Vacuum Chambers A and B, including safety measures and fire suppression systems, which ensure human safety for Artemis lunar missions;
  - Sustained deteriorating or failed physical assets based on mission relevancy, including chillers, air handlers, fire alarm panels, boilers, exhaust fans, roofs, roads, and various infrastructure system repairs;
  - Developed pre-emptive mitigation measures to reduce project cost and schedule impacts due to regulatory compliance activities; and
  - Conducted vertical motion simulations to develop scenarios and test cards in preparation for real, Advanced Air Mobility (AAM) flight tests with industry.

- Provided technical authority guidance, testing, and oversight to ensure health, safety, and stewardship of resources, including the environment:
  - Provided independent testing and simulation capabilities for all mission programs;
  - Provided Agency-wide technical assessment and independent evaluation of critical and high-risk mission systems through the NASA Engineering and Safety Center (NESC);
  - Issued guidance and policy on key health, safety, and engineering issues; and
  - Identified 100 Severity 1 and 2 software issues which, if manifested in operations, have the potential to result in the loss of mission or the loss of an essential mission capability.

- Supported Center engineering, safety, and operational needs, including independent technical support, investments in key Center needs, and leadership of Center and corporate functions:
  - Provided equipment and other investments to facilities, and other physical assets in response to evolving mission requirements;
  - Completed the Mars Transportation Architecture Study to support future mission work;
  - Supported the transference of revolutionary technologies to industry and other agencies through center engagements;
  - Supported safety and health operations for critical, onsite work across the Agency during the COVID-19 pandemic; and
  - Met safety, engineering, and environmental requirements specified in Space Act Agreements.

WORK IN PROGRESS IN FY 2022

- Enable mission success with secure, accessible, and leading-edge IT services, applications, and platforms:
  - Implement enterprise technologies, including virtual tools, to optimize work while enabling collaboration, productivity, and flexibility for NASA's hybrid workforce;
  - Enhance cybersecurity at NASA in alignment with Executive Order 14028 by removing barriers to threat information sharing between Government and the private sector; modernizing and implementing stronger cybersecurity standards; improving software supply chain security; establishing a cybersecurity safety review board; creating a standard playbook for cyber incident response; improving detection of cybersecurity incidents on Agency networks; and improving investigative and remediation capabilities;
  - Upgrade to modern IP-based voice communication infrastructures via the first Next Generation Mission Voice solution;
  - Formulate a Smart Centers pilot to explore leveraging of smart cities technologies (including IoT sensors, autonomous surveillance, data platforms, and digital twins) on our physical infrastructure to improve facility sustainability and planning; and
  - Expand the adoption and capabilities of the Enterprise Data Platform (EDP) by adding Intelligent Search to improve findability and expand access and analytics for mission datasets, translating into more efficient mission processes.

- Provide foundational business services to enable mission activities:
  - Execute the Agency's Strategic Workforce Plan to acquire the right talent for the highly technical mission work and consolidate contracts for increased efficiency;
  - Enhance employee opportunities for growth and development with NASA's Talent Marketplace, which empowers internal hiring for rapid response to mission needs; and
  - Lead the implementation of the Agency's DEIA strategy, including the utilization of critical workforce data and analytics.

- Maintain and enhance NASA's physical asset portfolio, including facilities, roads, and utilities, and commitment to environmental stewardship:
  - Continue Agency Master Plan (AMP) development to better understand the linkage between assets and missions through centers;
  - Reduce arc flash and layered pressure vessel system risk through ongoing mitigation, inspection, and testing;
  - Modernize the Arc Jet Complex for critical mission work requiring thermal protection systems;
  - Test wear and erosion for the Advance Electric Propulsion System (AEPS) thruster; and
  - Implement an Environmental Management Enterprise Strategic Plan to better protect natural resources and the environment Agency-wide.

- Provide technical authority guidance, testing, and oversight to ensure health, safety, and stewardship of resources, including the environment:
  - Provide independent testing and simulation capabilities for all mission programs;
  - Develop resources for employees to provide technical guidance and policy for consistent application of Engineering Technical Authority (ETA) across centers;
  - Continue to provide independent assessments, audits, and activities that support mission work, particularly those related to systems integration, health, and safety; and
  - Develop commercialization plan of low-Earth orbit (LEO) and lunar relay communications and navigation services.

- Support Center engineering, safety, and operational needs, including independent technical support, investments in key Center needs, and leadership of Center and corporate functions:
  - Continue to support calibrations, function tests, adjustments/alignments, repairs and other needs with the Metrology and Calibration Laboratory (MCL) at Marshall Space Flight Center (MSFC);
  - Continue studies supporting Agency priorities, such as lunar sustainability and planetary protection;
  - Conduct a Citizen Science project in support of the Artemis Campaign; and
  - Continue to address issues and requirements to ensure Center personnel are working in a safe environment, including issues related to COVID-19.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

- Enable mission success with secure, accessible, and leading-edge IT services, applications, and platforms:
  - Develop high cybersecurity encryption capability for classified and sensitive data;
  - Expand and enhance network security and accessibility; and
  - Implement new and improved enterprise licenses for key applications to increase security while enabling more virtual collaboration and productivity for the hybrid workforce.
- Provide foundational business services to enable mission activities:
  - Grow and acquire the right talent for current and future mission work;
  - Enhance operations with more digital capabilities, including automation and process improvement;
  - Improve the security architecture to protect human health and safety;
  - Scale NASA's broadcasting and sharing of mission content, focusing on underserved populations and the global climate conversation; and
  - Establish new international agreements and manage NASA's 600+ active international agreements.
- Maintain and enhance NASA's physical asset portfolio, including facilities, roads, and utilities, and commitment to environmental stewardship:
  - Continue enhancing physical asset managing with the installation of condition-based maintenance (CBM) technologies;
  - Implement NASA's plan to transition to an all-Zero Emission Vehicle (ZEV) fleet;
  - Support aircraft recapitalization and purchasing with oversight and capability expertise; and
  - Partner with NASA Aeronautics Research Institute to create a supply chain climate resiliency model in support of climate action planning.
- Provide technical authority guidance, testing, and oversight to ensure health, safety, and stewardship of resources, including the environment:
  - Provide independent testing and simulation capabilities for all mission programs;
  - Develop, maintain, and improve orbital debris environment models, tools, and algorithms to improve orbit predictions, understand spacecraft anomalies, and better interpret sensor data;
  - Provide baseline policy, oversight, training, and support functions, along with anticipated policy updates related to mission safety and assurance; and
  - Establish a new capability to assess and build relationships with high-volume industry-leading microelectronics manufacturers that supports the increased utilization of COTS devices in high-reliability aerospace applications.

- Support Center engineering, safety, and operational needs, including independent technical support, investments in key Center needs, and leadership of Center and corporate functions:
    - Lead Agency efforts to ensure continued scientific rigor and integrity;
    - Make critical strategic investments in laboratories, technical equipment, and facilities aligned with Agency goals and objectives;
    - Focus on increased Tenant Occupancy and collaboration with industry;
    - Work with industry through Space Act Agreements and Broad Agency Announcements (BAA) to leverage the technology for the MC2 Prototype Engine; and
    - Provide competitively selected "seed funding" opportunities to our civil servant workforce to develop concepts, develop technological capabilities, and provide leadership opportunities with the broader scientific community.

Themes

MISSION SERVICES AND CAPABILITIES

Mission Services and Capabilities (MSaC) provides enterprise solutions under three programs: Information Technology, Mission Enabling Services, and Infrastructure and Technical Capabilities. Strategically, these programs meet workforce, infrastructure, information technology, and business operations requirements necessary to enable NASA's mission. MSaC ensures that critical Agency operations are effective, efficient, safe, and meet statutory, regulatory, and fiduciary responsibilities. These mission enabling services, capabilities, and related processes provide efficient and effective administration across all NASA centers.

ENGINEERING SAFETY AND OPERATIONS

Engineering, Safety, and Operations (ESO) provides for the ongoing management and operations of NASA Headquarters, nine centers, and component facilities under two programs: (1) Agency Technical Authority and (2) Center Engineering, Safety, and Operations. The programs support scientific and engineering activities. They contribute to the reduction of program risks by ensuring that: technical skills and assets are ready and available to meet program and project milestones; mission and research endeavors are technically and scientifically sound; and center practices are safe and reliable, including the highly skilled staff and specialized infrastructure at the centers that facilitate NASA missions.

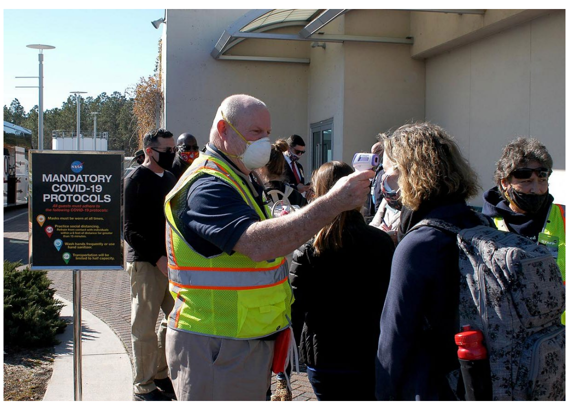
MISSION SERVICES & CAPABILITIES

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Information Technology (IT)	548.6	612.2	**667.4**	680.8	694.4	708.3	722.5
Mission Enabling Services	702.5	731.5	**761.2**	776.4	792.0	807.8	823.9
Infrastructure & Technical Capabilities	667.2	685.1	**725.8**	740.3	755.1	770.2	785.6
Total Budget	**1,918.3**	**2,028.8**	**2,154.4**	**2,197.5**	**2,241.5**	**2,286.3**	**2,332.0**
Change from FY 2022 Budget Request			**125.6**				
Percent change from FY 2022 Budget Request			**6.2%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



Employees continue critical onsite mission work, seen here, testing the Space Launch System (SLS) rockets, while staying safe through a collaboration of effective Agency communication, facility management, HR services, and technical authority support.

Mission Services and Capabilities (MSaC) provides foundational business service and enterprise solutions to all of NASA. While mission requirements evolve with Agency priorities and external conditions, MSaC is focused on the permanent and critical essentials that enable all NASA activity.

MSaC offers a range of foundational services, including, but not limited to, human capital, financial management, physical asset management, software and hardware services, communications, diversity and inclusion programs, legal services, small business program, procurement services, and safety/protective services. MSaC is broken up into three programs: Information Technology (IT), Mission Enabling Services (MES), and Infrastructure and Technical Capabilities (I&TC).

MSaC Priorities

MSaC provides foundational business services, which remain a permanent requirement as missions and conditions evolve. Permanence, however, does not mean static. MSaC is focused on ensuring the delivery of quality services, improving the customer experience for Centers and missions, and transforming business to ensure agility, efficiency, and effectiveness as requirements evolve. NASA's long-term success will depend on a foundation of reliable support services that are responsive to mission requirements in real time and streamlined to minimize cost while maximizing impact.

MSaC ensures services and infrastructure are mission-ready and keeping pace with industry standards so that NASA can continue to lead the world in space exploration, scientific discovery, and aerospace research. MSaC not only must provide for immediate mission needs, but also must anticipate future needs and potential emergent conditions that would impact Agency goals. Business essentials, like finance, IT, human capital management, and legal services, form the bedrock of NASA operations, while efforts to transform service and improve customer experience are imperative to support NASA into the future.

EXPLANATION OF MAJOR CHANGES IN FY 2023

See each program area for a description of significant changes.

ACHIEVEMENTS IN FY 2021

See each program area for a complete list of achievements in FY 2021 for IT, MES, and I&TC.

WORK IN PROGRESS IN FY 2022

See each program area for a complete list of work in progress in FY 2022 for IT, MES, and I&TC.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

See each program area for a complete list of planned achievements in FY 2023 for IT, MES, and I&TC.

Program Elements

INFORMATION TECHNOLOGY

The IT Program provides the information services needed to fulfill NASA's multifaceted missions and operations, including cybersecurity, IT asset planning and management, and technical support. NASA's Information Technology Program helps improve Agency outcomes by accelerating results through tools that increase productivity; sharing NASA's data and discoveries; and increasing the quality, resiliency, and cost-effectiveness of its information systems. Reliable, adaptable, and secure cloud-based IT is increasingly important to NASA's mission portfolio because it is a key enabler for advances in science, technology, aeronautics, and space exploration.

MISSION ENABLING SERVICES

The MES Program provides an enterprise approach to managing NASA's business operations and mission support activities. Missions rely on these institutional services to provide the business services and skilled staff required to accomplish their objectives. Enterprise management of these areas ensures that critical Agency operations are effective, efficient, and meet statutory, regulatory, and fiduciary responsibilities. Business services include financial management, human capital management, procurement, small business, legislative affairs, equal opportunity and diversity management, legal, communications, international and interagency relations, and protective services.

MISSION SERVICES & CAPABILITIES

INFRASTRUCTURE AND TECHNICAL CAPABILITIES

The I&TC Program provides sustainment, operations, and maintenance for facilities and technical capabilities. The program also provides effective oversight and management of real property, environmental program activities, aircraft operations, and logistics functions. These capabilities enable NASA to meet its statutory and regulatory responsibilities and ensures that the right infrastructure is available to meet mission requirements. This mission is accomplished through effective management of assets and capabilities, proactive coordination with NASA mission directorates, institutional planning, proactive deployment of sustainable practices, ongoing regulatory compliance, and reducing current and future infrastructure-related risks.

INFORMATION TECHNOLOGY (IT)

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**548.6**	**612.2**	**667.4**	**680.8**	**694.4**	**708.3**	**722.5**
Change from FY 2022 Budget Request			**55.2**				
Percent change from FY 2022 Budget Request			**9.0%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Working from home during the pandemic, like this employee from Marshall Space Flight Center (MSFC), has been enabled with leading-edge collaboration tools and network expansions. The Agency has maintained mission progress despite the unprecedented challenges of COVID.

NASA's Information Technology (IT) program provides secure connectivity and data access for the NASA workforce and its partners, deploying over 100,000 continuous diagnostics and mitigation (CDM) tools across the corporate and mission networks; protecting Government data from approximately 5.3 billion cyber-attacks per day. The program provides NASA end-users with cloud-based email inboxes and collaboration capabilities. Additionally, the IT program supports over 250 applications that empower scientific research, enables mission success, and provides data access to achieve new discoveries.

IT Priorities

NASA's inspiring missions are evolving as scientific discovery and human presence extends to the Moon and beyond. Existential conditions, like commercial industry, global competitors, expanding data capacity requirements, disruptive conditions (e.g., climate change, natural disasters, and pandemics) and fast-evolving mission requirements challenge NASA's traditional IT support approach. Technology, data, and collaboration across organization and geographic boundaries is imperative to NASA's immediate mission goals and long-term organizational health. In addition to providing a foundation of service that empowers NASA with technology solutions, equipment, software, and support services, the IT program aligns to the mission support management goals and objectives as follows:

- Service Delivery: provide expert technical and professional support services and capabilities to NASA’s missions.
  - Maintain and modernize NASA assets, including physical and IT infrastructures, to meet mission needs; and
  - Protect and securely share NASA’s critical data, information, and knowledge to enable mission success.

INFORMATION TECHNOLOGY (IT)

- Customer Experience: create and maintain a premium customer experience for NASA's mission directorates and centers.
  - Ensure ongoing engagement with customers to understand, integrate, and prioritize evolving customer needs and service requirements;
  - Promote diversity, inclusion and engagement in the workforce and work environment reflective of NASA's core values; and
  - Target, anticipate, and exceed customer needs using data.
- Agility and Innovation: create an environment of continuous transformation and stewardship resulting in more efficient and effective operations.
  - Prioritize investment in projects that enhance, transform, and reduce costs of service delivery;
  - Utilize data-driven processes for prioritizing and integrating work, risk, resources, and decision making;
  - Streamline services and shift from low-value to high-value work by eliminating unnecessary work, optimizing critical work, and automating wherever possible; and
  - Create cyber-physical workspaces and solutions that support distributed work teams and flexible work environments.

EXPLANATION OF MAJOR CHANGES IN FY 2023

In FY 2023, SSMS modernization will provide for critical upgrades and extensions of IT systems and infrastructure. Improvements include: (1) implementation of high cybersecurity encryption and credentialing to ensure protections for classified and highly sensitive data, including International Traffic in Arms (ITAR) and Export Administration Regulations (EAR) data; (2) development and adoption support for Future of Work applications that empower a hybrid and geographically dispersed workforce; (3) network expansion and improvements to ensure secure and high-speed accessibility; (4) decommissioning physical data centers to transition to cloud operations; and (5) licensing and software upgrades to enhanced security and operational capability; (6) implementing the IT Supply Chain Risk Management program to evaluate and assess software and IT hardware components for Federal and Agency cybersecurity regulation and policy compliance.

ACHIEVEMENTS IN FY 2021

Service Delivery

The IT program delivered the technical and professional services to provide and support technology, applications, and IT infrastructure for all mission activity.

- Maintained and modernized NASA assets, including physical and IT infrastructures, to meet mission needs.
  - Provided foundational IT support services for all NASA missions including the operation of over 200 applications, 3,000 websites, and supported over 36 mission-critical events through telecommunications;
  - Continued to operate the Mission Communications Program (CP) NASA Communications (NASCOM) Mission Backbone (NMB) and provided critical support to numerous critical launches and events, including Commercial Crew, ISS resupply, Soyuz, LUCY, and ISS EVAs;

INFORMATION TECHNOLOGY (IT)

- Continued to utilize business application and Enterprise Data Platform with Tableau/Power Business Intelligence (BI) software for data integration, intelligent automation of business processes, and Internet of Management Things;
- Responded to COVID-19 telework conditions, including the dramatic increase in use of Agency's Virtual Private Network (VPN), as well as provided on-site 24/7 communications support for critical Agency spacecraft operations; and
- Enhanced management of IT assets, including enabling higher shared bandwidth by aggregating individual network connections, as well as implementing a Configuration Management Database to manage assets on an enterprise level.

- Protected and securely shared NASA's critical data, information, and knowledge to enable mission success.
  - Continued to grow and staff the NASA Security Operations Center (SOC) Continuity of Operations capability 24/7 to maintain critical cybersecurity service operations;
  - Modernized NASA's in-memory database platform for vendor transactions, enhancing NASA's financial system, contract writing system, and business intelligence platform;
  - Operated a cloud-based platform for next generation Scientific and Technical Information (STI)/NASA Technical Reports Server (STI/NTRS) System. This data is used extensively in the Science community to further advance scientific discoveries;
  - Responded to COVID-19 telework conditions by developing, implementing, and enforcing accelerated cybersecurity engineering authentication and secure network capabilities;
  - Improved IT data access for multiple stakeholders. Examples include meeting intensive data storage needs of the Artemis Campaign by moving to a common cloud platform and minimizing local infrastructure cost by migrating to Agency-wide cloud solutions; and
  - Enhanced reliability and security of IT assets and capabilities through Network Asset Control enforcement, eliminating cybersecurity vulnerabilities by removing unauthorized software, and Application Control security policies on all IT firewalls.

Customer Experience

The IT program created and maintained a premium experience for NASA's mission directorates and centers.

- Ensured ongoing engagement with customers to understand, integrate, and prioritize evolving customer needs and service requirements.
  - Enhanced IT experience for NASA stakeholders and employees by improving the use of Artificial Intelligence and Machine Learning across the Agency as well as eliminating redundancies and increasing efficiencies through an Enterprise IT operating model; and
  - Enhanced IT capabilities through accelerated adoption of workplace and collaboration tools such as Microsoft Teams in response to COVID-19. These capabilities also served as a permanent enhancement of NASA's enterprise capabilities.

- Targeted, anticipated, and exceeded customer needs using data.
  - Leveraged survey inputs and COVID dashboard to continue to respond to work-from-home needs by providing critical teleworking technologies, virtual environments, and support services that enabled high productivity.

Agility and Innovation

IT created and supported an environment of continuous transformation and stewardship, resulting in more efficient and effective operations.

INFORMATION TECHNOLOGY (IT)

- Prioritized investment in projects that enhance, transform, and reduce costs of service delivery.
  - Partnered with NASA missions to implement novel technology including the design of the NASCOM Mission Next Generation Voice system, isolated testing environments, and architecture solutions to support cloud computing services; and
  - Trained 70 percent of Applications Division staff in Scaled Agile Framework for Lean Enterprises and launched initial Agile Release Training to align business value and outcomes to OCIO provided services.
- Utilized data-driven processes for prioritizing and integrating work, risk, resources, and decision making.
  - Continued to develop Artificial Intelligence for improved metadata and searchability of crucial NASA data on NASA websites.
- Streamlined services and shift from low-value to high-value work by eliminating unnecessary work, optimizing critical work, and automating wherever possible.
  - Established a single enterprise robotic process automation (RPA) service to facilitate robotic operations against enterprise and/or center-level applications or tools.
- Created workspaces enabled with 21st century technology, virtual environments, and solutions that support distributed work teams and flexible work environments.
  - Launched the Enterprise Digital Transformation (EDT) strategic initiative to aggressively harness digital advances to accelerate and unify our collective efforts to transform NASA.

WORK IN PROGRESS IN FY 2022

Service Delivery

The IT program delivers the technical and professional services to provide and support technology, applications, and IT infrastructure for all mission activity.

- Maintain and modernize NASA assets, including physical and IT infrastructures, to meet mission needs.
  - Enhance management of IT assets including implementation of low-code application platforms to speed NASA application development, improve IT architecture for data-related analysis, establish streamlined IT acquisition, and consolidate local IT contract.
- Protect and securely share NASA's critical data, information, and knowledge to enable mission success.
  - Expand data access through consolidated cloud-based platforms to support key flight missions and incorporate Earth Science data (several hundred petabytes);
  - Expand the adoption and capabilities of the Enterprise Data Platform (EDP) by adding Intelligent Search to improve findability and expand access and analytics for mission datasets, translating into more efficient mission processes;
  - Enhance reliability and security of IT assets and capabilities by isolating applications across the network to improve security, enhance software patch management, and continue consolidation of cybersecurity logging capability;
  - Enhance cybersecurity in response to SolarWinds incident through improved Microsoft O365 licensing to secure 'work from home' environment, secure access to IT through authentication enhancements, modernized firewalls, and improved threat detection;

INFORMATION TECHNOLOGY (IT)

- Respond to SolarWinds incident by implementing Data Logging and Cybersecurity Analytics platform. This will streamline core capabilities to meet increased data needs, aggregate logs, provide malware analysis, and incident management enhancements;
- Fully implement the Controlled Unclassified Information (CUI) Program, including user training and ensuring physical and technical safeguarding of CUI data; and
- Identify critical cybersecurity requirements to improve, cyber hygiene, zero-trust, supply chain risk management, event logging, and endpoint detection and response, per Presidential Executive Order 14028.

Customer Experience

The IT program creates and maintains a premium experience for NASA's mission directorates and centers.

- Ensure ongoing engagement with customers to understand, integrate, and prioritize evolving customer needs and service requirements.
  - Improve customer and employee experience by expanding cloud-based solutions, Agency-wide intranet deployment, and new Customer Experience strategies in partnership with the Mission Support Directorate.

Agility and Innovation

IT creates and supports an environment of continuous transformation and stewardship, resulting in more efficient and effective operations.

- Prioritize investment in projects that enhance, transform, and reduce costs of service delivery.
  - Transition NASA Mission and Corporate communications services from NICS (NASA Integrated Communications Services) contract to Agency Enterprise Global Information Technology Solutions (AEGIS) contract to assist in computing and communications transformations;
  - Consolidate disparate cybersecurity services into an enterprise-wide contract (CyPrESS) to improve cost effectiveness while strengthening cybersecurity;
  - Implement MGT Act IT Working Capital Fund (WCF) for modernization with new WCF and transfer authorities. Continue IT contracts transition to the enterprise from centers as appropriate to promote cost savings while optimizing unique, local services; and
  - Upgrade to modern IP-based voice communication infrastructures via the first Next Generation Mission Voice solution replacing NASA's aging Mission-critical voice communications system which was deployed during the Shuttle era.

- Utilize data-driven processes for prioritizing and integrating work, risk, resources, and decision making.
  - Partner with NASA Mission communities in the transition of GSA Networx Mission-critical services to the Enterprise Infrastructure Solutions (EIS) contract, as mandated under FITARA and by OMB; and
  - Establish a draft framework for an interoperable NASA Digital Engineering Environment that will allow internal/external engineers to seamlessly team on complex engineering design, analysis, and test workflows

- Streamline services and shift from low-value to high-value work by eliminating unnecessary work, optimizing critical work, and automating wherever possible.

INFORMATION TECHNOLOGY (IT)

  - Baseline automated Smart Reviews to streamline preparation for and improve real-time, data-driven discussions for more effective program/project reviews, leading to earlier detection and resolution of issues.

- Create workspaces enabled with 21st century technology, virtual environments, and solutions that support distributed work teams and flexible work environments.
  - Installation of NASCOM Mission Next Generation Voice system, isolated testing environments, and architecture solutions to support cloud computing services;
  - Support novel technology development with NASA missions by providing enhanced voice, video, network services, and maintain NASCOM connectivity between flight projects and space communications supporting increased flight tempo;
  - Formulate a Smart Centers pilot to explore leveraging of smart cities technologies (including IoT sensors, autonomous surveillance, data platforms, and digital twins) on our physical infrastructure to improve facility sustainability and planning; and
  - Test Modern & Inclusive Collaboration Spaces (MICS) to learn and norm effective and fully inclusive on/off-site hybrid teaming collaboration tools and behaviors.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

Service Delivery

The IT program delivers the technical and professional services to provide and support technology, applications, and IT infrastructure for all mission activity.

- Maintain and modernize NASA assets, including physical and IT infrastructures, to meet mission needs.
  - Expand high-speed network accessibility;
  - Improve Mission and Corporate Network Communications by updating the nine centers and Headquarters outdated servers and networks to one Agency enterprise network operating at current required mission standards;
  - Continue migration of center end points to the new intent based, Zero Trust Network Architecture (ZTNA) compliant Software Defined Network fabric as well as transition operations to newly deployed Software Defined Access infrastructure;
  - Enhance licensing and software with upgrades that increase security and operational capability; and
  - Implement enterprise network operations modernization through transition to NetSecOps operations methodologies and practices and building cyber response capabilities into the current network operations landscape.

- Protect and securely share NASA's critical data, information, and knowledge to enable mission success.
  - Implement the IT Supply Chain Risk Management program to evaluate and assess software and IT hardware components for Federal and Agency cybersecurity regulation and policy compliance, such as components made in China and FedRAMP certified software;
  - Implement high cybersecurity encryption and credentialing for classified and sensitive data;
  - Once the NISAR (NASA-ISRO [Indian Space Research Organization] Synthetic Aperture Radar) mission is launched, downlink high volumes of NISAR mission data directly to the cloud and deliver in near real time to scientists;

INFORMATION TECHNOLOGY (IT)

- Continue implementation of consolidated enterprise cybersecurity contract (CyPrESS) and establish a single enterprise third party penetration testing and assessment/authorization service, significantly reducing vulnerabilities across NASA systems;
- In response to Presidential Executive Order 14028 - enhance IT logging platform to meet OMB defined IT event logging maturity, thereby increasing visibility for NASA's SOC to appropriately identify, detect, and respond to a variety of IT incidents;
- Provide Agency intelligent search capability with well-defined processes to connect to existing data sources; and
- Preserve NASA records in digital formats according to Federal records management policies and best practices.

Customer Experience

The IT program creates and maintains a premium experience for NASA's mission directorates and centers.

- Ensure ongoing engagement with customers to understand, integrate, and prioritize evolving customer needs and service requirements.
  - Continue engagement activities to identify value-add improvements to IT services and applications;
  - Provide adoption support to customers to optimize the use of IT applications and virtual technologies;
  - Target, anticipate, and exceed customer needs using data; and
  - Develop a marketplace for approved applications. Consolidate internal and external websites across the Agency. Develop/refine Agency Application intake process.

Agility and Innovation

IT creates and supports an environment of continuous transformation and stewardship, resulting in more efficient and effective operations.

- Prioritize investment in projects that enhance, transform, and reduce costs of service delivery.
  - Continue to innovate with industry to provide new services and offerings such as HoloLens.
- Utilize data-driven processes for prioritizing and integrating work, risk, resources, and decision making.
  - Pilot automated Smart Reviews at centers to streamline preparation for and improve real-time, data-driven discussions for more effective program/project reviews, leading to earlier detection and resolution of issues.
- Streamline services and shift from low-value to high-value work by eliminating unnecessary work, optimizing critical work, and automating wherever possible.
  - Decommission physical data centers to transition to cloud operations.
- Create workspaces enabled with 21st century technology, virtual environments, and solutions that support distributed work teams and flexible work environments.
  - Develop "Future of Work" Applications to transition away from outdated applications such as excel spreadsheets and pivot tables and transition to more sophisticated applications to support the needs of the Artemis Generation and Moon-to-Mars.

INFORMATION TECHNOLOGY (IT)

Program Elements

ENTERPRISE IT

The Enterprise IT program is multifaceted and includes the following six project elements, each with unique functions and work focus:

- Applications: anticipates and aligns customer requirements with solutions that best meet Agency needs by delivering secure, sustainable applications quickly and cost effectively, establishing a platform-centric architecture that empowers mission support, enhanced software management to reduce software license costs, and continuous portfolio rationalization.
- Communications: NASA's enterprise service provider for fully managed network and communications services supporting institutions, programs and projects located at the NASA centers. Communications is also responsible for maintaining, operating, and continually evolving services to improve delivery capabilities, strengthen NASA's cybersecurity posture, and reduce costs.
- Computing Services: brokers commercial cloud computing services for the NASA community and provides oversight of NASA's compliance with the Federal Data Center Optimization Initiative. Cloud computing services extends to all NASA missions, mission support, and to external collaborators.
- End User Services (EUS): provides high-quality, reliable, cost-effective service desk, end-user computing services, collaboration, content management systems, and services in support of all NASA Federal and contractor employees, including support for laptops, desktops, mobile devices, printing, email, messaging, help desk services, software patching, distribution, and more.
- Information Management (IM): provides NASA with framework, guidelines, and services to ensure secure and efficient access, use, analysis, and preservation of the Agency's information resources. The program ensures NASA's compliance with Federal statutes relating to data access and integrity.
- Transformation and Data: engages the brightest minds across the Agency to guide NASA's data strategy, technology infusion, and strategic investment decisions, and identifies emerging information technologies to support NASA's needs most effectively in a rapidly changing world.

SAFEGUARDING DATA AND IT ASSETS

NASA OCIO is responsible for Agency cybersecurity policy and the implementation and management of enterprise cybersecurity and privacy services. The budget is aligned to the National Institute of Standards and Technology (NIST) Cybersecurity Framework to evaluate cybersecurity gaps and investments against the NIST cybersecurity functions: Identify, Detect, Protect, Respond, and Recover. This alignment allows the Agency to make strategic investments to develop, modernize, and enhance Agency cybersecurity capabilities to address the greatest areas of risk to the Agency, its missions, and supporting functions.

IT GOVERNANCE AND OVERSIGHT

NASA OCIO provides Agency-level capabilities for intentionally managing IT and meeting Agency and Federal requirements. IT Governance & Oversight efforts involve collaborating with stakeholders across

INFORMATION TECHNOLOGY (IT)

the Agency to formulate plans and manage budgetary data to meet legal mandates, OMB requirements and guidance, Executive Orders, and regulations. These efforts also include the E-Government activities and Federal CIO Council Committees in which NASA participates.

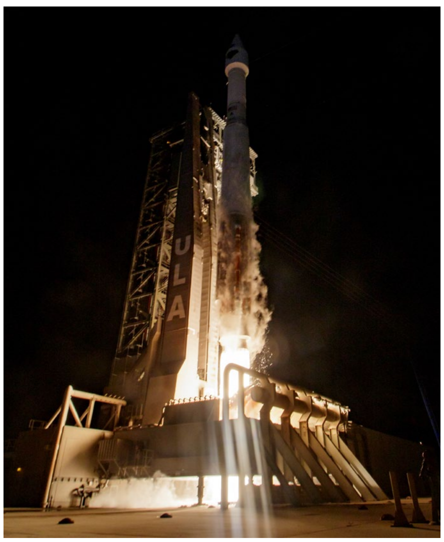
MISSION ENABLING SERVICES

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**702.5**	**731.5**	**761.2**	**776.4**	**792.0**	**807.8**	**823.9**
Change from FY 2022 Budget Request			**29.7**				
Percent change from FY 2022 Budget Request			**4.1%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



The launch of the United Launch Alliance (ULA) Atlas V rocket (shown here) with the Lucy spacecraft aboard demonstrates the collaborative support of mission services, like the international relations and legal services needed to form these relationships and communications to share them with the world.

Mission Enabling Services (MES) ensure NASA mission success with foundational support services, using enterprise service delivery to enhance problem solving and agile responses to evolving requirements. Using an enterprise approach, the MES Program eliminates duplicative capabilities, provides opportunities for employees to collaborate across geographic boundaries, and remains agile to shifting demands and surge requirements. Missions rely on MES's institutional capabilities to accomplish their objectives. Enterprise management ensures that critical Agency operations are strategic, mission-focused, agile, and streamlined.

Approximately 82 percent of the MES budget supports labor costs associated with nearly 2,000 civil servants and 1,500 support contractors who provide critical services to the Agency. Recruiting, hiring, and maintaining the right mix of high-performing talent remains a critical focus for the MES Program.

MES provides NASA with a bedrock of business functionality in human capital; financial management; procurement; protective services; small business; diversity and equal opportunity programs; legislative affairs; communications; and international and interagency.

MES Priorities

MES comprise business support that spans the Agency. Set by the Mission Support Directorate (MSD), the following management goals and objectives align to MES functions, driven by mission requirements and Agency priorities:

- Service Delivery: provide expert technical and professional support services and capabilities to NASA's missions.

MISSION ENABLING SERVICES

  - Manage programs to ensure the health, safety, and security of NASA people, property, and the public while enabling mission success through technical excellence;
  - Securely share and utilize data, information, and knowledge with NASA stakeholders; and
  - Continuously improve NASA employee talent management to remain competitive for top talent and provide constant professional growth to the workforce.

- Customer Experience: create and maintain a premium customer experience for NASA's mission directorates and Centers.
  - Ensure ongoing engagement with customers to understand, integrate, and prioritize evolving customer needs and service requirements;
  - Promote diversity, inclusion and engagement in the workforce and work environment reflective of NASA's core values; and
  - Target, anticipate, and exceed customer needs using data.

- Agility and Innovation: create an environment of continuous transformation and stewardship resulting in more efficient and effective operations.
  - Prioritize investment in projects that enhance, transform, and reduce costs of service delivery;
  - Utilize data-driven processes for prioritizing and integrating work, risk, resources, and decision making;
  - Streamline services and shift from low-value to high-value work by eliminating unnecessary work, optimizing critical work, and automating wherever possible; and
  - Create workspaces enabled with 21st century technology, virtual environments, and solutions that support distributed work teams and flexible work environments.

EXPLANATION OF MAJOR CHANGES IN FY 2023

The MES will support greater investments in Agency security infrastructure and processes to keep pace with threats and technology. In FY 2023, MES funding will provide for (1) fire safety upgrades; (2) access control upgrades; (3) security system upgrades to integrate with national information systems; and (4) on-boarding and off-boarding process improvements, including badging, background checks, Personal Identity Verification (PIV) systems, and physical access infrastructure at sites and facilities (Enterprise Physical Access Control System or EPACS). MES funding also provides the labor for increased activity to support the Agency's focus on diversity, equity, inclusion, and accessibility (DEIA). In FY 2023, DEIA activities include updating executive performance requirements with DEIA targets, issuing NASA procedural requirements on procedural accommodations, and former additional collaborations with minority serving institutions (MSIs).

ACHIEVEMENTS IN FY 2021

Service Delivery

Provided expert technical and professional services and capabilities to support NASA's missions.

- Managed programs to ensure the health, safety, and security of NASA people, property, and the public while enabling mission success through technical excellence.
  - Established a process, using the Microsoft Teams application, to conduct virtual PIV badge renewals supporting minimal in-person interactions;
  - Modernized NASA's Enterprise Physical Access Control System (EPACS) infrastructure to reduce the costs of licensing and operations, while ensuring safety across centers; and

MISSION ENABLING SERVICES

  - Developed COVID-19 contact tracing dashboards and capabilities.

- Protected and securely shared NASA's critical data, information, and knowledge to enable mission success.
  - Coordinated within the United States Government (USG) on significant topics of cross-cutting policy interest and led engagement on NASA contributions to broad interagency, national security, foreign policy objectives, and impacts to NASA activities of USG policies and practices (e.g., export control restrictions, sanctions, and directives).

- Continuously improved NASA employee talent management to remain competitive for top talent and provide constant professional growth to the workforce.
  - Developed and launched the Agency-wide Learning and Development Needs Assessment tool and upgraded the SATERN learning tool for enhanced and targeted professional growth;
  - Negotiated the legality of major and unprecedented acquisitions and contracting for critical mission work, including the Power Propulsion Element, Gateway Logistics Services, Human Landing System, habitation modules, and Commercial Lunar Payload Services;
  - Utilized Talent Marketplace for internal work rotations and details, allowing supervisors to provide employee development opportunities to about 18,000 employees across the Agency;
  - Utilized the Astronaut Selection Tool to review and assess over 12,000 applications for the 2021 Astronaut selection process;
  - Completed phase 1 implementation of the new hiring transformation initiative, establishing the Talent Acquisition and Learning Office (TALO), and improving processes to reduce average hiring time by 29 days;
  - Developed a Workforce Management Strategy that is committed to meeting and supporting Federal/Agency requirements, initiatives, goals, and objectives for a measurably lower total cost of ownership, while remaining agile;
  - Deployed a revamped Chief Financial Officer (CFO) University curriculum, including six new courses, and through virtual learning, we reached over 3,000 trainees in FY 2021, up from approximately 300 in fiscal year prior to the pandemic;
  - Led the coordination and development of the Agency's inaugural Learning Agenda, as required under the recently enacted Foundations for Evidence-based Policymaking Act; and
  - Coordinated the development of the Agency's inaugural Capacity Assessment, as well as its Annual Evaluation Plan (AEP) for FY 2023.

Customer Experience

Create and maintain a premium customer experience for NASA's mission directorates and Centers.

- Ensured ongoing engagement with customers to understand, integrate, and prioritize evolving customer needs and service requirements.
  - Conducted 12 webinars and participated in 70 outreach events with industry, to promote small business engagement with NASA, with a goal of increasing equity, inclusion, and accessibility;
  - Planned and implemented sustained, strategic engagement with international partners in support of specific, growing requirements for NASA programs and as part of the design and development of the Agency's future exploration and Earth Science activities, through the establishment of 64 new international agreements and management of over 600 active international agreements;
  - Produced the 2021 Spinoff Report, sharing NASA's value to the American taxpayer through scientific and technological breakthroughs that improve daily living;

MISSION ENABLING SERVICES

  - Developed and navigated the complex legal framework of the Space Act Agreements to foster industry and drafted unique contracts now used to obtain the commercial services, heralding a new era of American space flight and commercial development;
  - Advanced USG and NASA objectives through the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS);
  - Oversaw NASA's advisory committees, commissions, and panels, including the Administrator-level NASA Advisory Council (NAC), NASA Aerospace Safety Advisory Panel (ASAP) and International Space Station Advisory Council (ISSAC), and produced the 2020 ASAP annual report;
  - Supported bilateral and multilateral engagement by NASA senior leaders to advance cooperative activities and establish and enhance relationships with international and interagency partners;
  - Showcased the return of launching American astronauts to space from American soil on American-built spaceships through broadcasting and online content;
  - Announced the FY 2020 NASA Small Business Administrator's Cup Award Winner;
  - Announced the FY 2020 Agency Level Winners for the Small Business Industry Award and Small Business Advocate Awards; and
  - Obtained permanent membership on the Procurement Control Board.

- Promoted diversity, inclusion, and engagement in the workforce and work environment reflective of NASA's core values.
  - Developed DEIA performance requirements for all executives, managers, and supervisors to ensure Agency-wide accountability and progress toward equity and inclusion goals;
  - Developed new DEIA Policy Statement, Gender Identity and Transition Guidance, Anti-Harassment Procedures, and Administrator messages recognizing each annual special observance;
  - Completed an HBCUs/MSIs Technology Infusion Road Tour event;
  - Broadcast the societal impacts of NASA's investment in climate research, include underserved populations, using current and emerging tools;
  - Executed resolution agreements with Louisiana State University; as well as a remediation plan for the Science Museum of Minnesota to correct civil rights deficiencies in their STEM programs, with full commitments for implementation of all corrective actions and continued compliance monitoring;
  - Initiated a trigger analyses of workforce representation by demographic groups and disability status, focusing on (a) overall workforce composition, (b) senior workforce composition, (c) occupations, (d) promotions, and (e) attrition rates; and
  - Negotiated the legality of major and unprecedented acquisitions and contracting for critical mission work, including the Power Propulsion Element, Gateway Logistics Services, Human Landing System, habitation modules, and Commercial Lunar Payload Services.

- Targeted, anticipated, and exceeded customer needs using data.
  - Coordinated the development of the Agency's inaugural Capacity Assessment, as well as its Annual Evaluation Plan (AEP) for FY 2023.

Agility and Innovation

Create an environment of continuous transformation and stewardship resulting in more efficient and effective operations.

- Prioritized investment in projects that enhance, transform, and reduce costs of service delivery.
  - Consolidated executive learning and development as an enterprise organization, resulting in ~$400K in savings;

MISSION ENABLING SERVICES

- Created a new application to enable enterprise reconciliation and reporting processes; and
- Co-led the development of the Agency's 2022 Strategic Plan, a Government Performance and Results Modernization Act (GPRAMA) mandated product.

- Utilized data-driven processes for prioritizing and integrating work, risk, resources, and decision making.
  - Implemented new capability for Agency Pulse Surveys to enable fast-cycle delivery and high-fidelity analysis of workforce perspectives on critical issues to better support employees;
  - Recognized by Association of Government Accountants for Excellence in Fiscal Accountability Reporting; and
  - Established field Center Chief Counsel lines of reporting to drive increased efficiencies with new governance, operations and legal knowledge management that enable sharing legal resources across the Agency.

- Streamlined services and shifted from low-value to high-value work by eliminating unnecessary work, optimizing critical work, and automating wherever possible.
  - Implemented NASA's Legal Enterprise Operating System (LEOS) to modernize legal knowledge management and consolidate work products, data, and case records;
  - Implemented "Resume to Desk Hiring Transformation" and improved talent acquisition by creating a shared certificate capability and advancing staffing data integration;
  - Co-managed NASA's inaugural Bot-A-Thon to promote adoption of robotic process automation (RPA), upskill the NASA workforce, and expand the use of RPA in business processes;
  - Created a secure, automated process for the delivery of electronic background investigation records to reduce data sprawl and processing time;
  - Established an agreement and integration with the Office of the Director of National Intelligence (ODNI) to automate the process for receiving continuous security evaluation alerts; and
  - Automated the adjudication of security investigation results with no issues, reducing workload and fatigue and allowing the adjudication workforce to focus on problem cases.

- Created workspaces enabled with 21st century technology, virtual environments, and solutions that support distributed work teams and flexible work environments.
  - Launched NASA's first online Digital Academy for one-stop-shop learning with over 200 self-paced courses on key areas related to a hybrid workspace, virtual engagement, and online collaboration;
  - Purchased industry training for combination virtual and in-person meetings, or "hybrid", to enhance overall employee performance and adapt to new and flexible working conditions;
  - Modernize the enterprise physical access control system to support standard operations at all centers and virtual access from multiple device and location types; and
  - Support Agency-wide supervisor cohort with training.

WORK IN PROGRESS IN FY 2022

Service Delivery

Provide expert technical and professional services and capabilities to support NASA’s missions.

- Manage programs to ensure the health, safety, and security of NASA people, property, and the public while enabling mission success through technical excellence; and

MISSION ENABLING SERVICES

  - Develop and operate process to review and adjudicate requests for disability and religious reasonable accommodations relating to COVID-19 vaccination exceptions.

- Protect and securely share NASA's critical data, information, and knowledge to enable mission success.
  - Continue using modern broadcasting and dissemination capabilities to share NASA discoveries, science, and other content with the world;
  - Participate in, and contribute facts to, global conversations around science, climate change, and green technologies;
  - Leverage intellectual property resources to support the patenting of new technology that has commercial viability and enable the transfer of such technology through negotiation and execution of license agreements;
  - Coordinate among the USG on significant topics of cross-cutting policy interest and leading USG engagement on NASA contributions to broad national security and foreign policy objectives and on impacts to NASA activities of USG policies and practices (e.g., export control restrictions, sanctions);
  - Continue to provide enabling advice and assistance on cyber security to include helping identify and implement key requirements of the Federal Information Security Modernization Act of 2014 (FISMA);
  - Continue to enable NASA to be a key contributor to the interagency focus on national security and the new approaches being fostered by National Security Presidential Memorandum (NSPM) 33; and
  - Coordinate the various evaluations included within NASA's Annual Evaluation Plan, culminating in an Annual Evaluation Report, which will be included in the Volume of Integrated Performance that will publish in February 2023.

- Continuously improve NASA employee talent management to remain competitive for top talent and provide constant professional growth to the workforce.
  - Execute strategic acquisition strategy by awarding one of three Regionalized service contracts and the Agency Fire Contract;
  - Continue current strategic acquisition strategy by soliciting offers for remaining two Regional Security services contracts;
  - Execute contracts for common services across the Agency through awards of Agency-wide or regional contracts that streamline services and reduce costs;
  - Standup the due diligence capability to determine NASA contractor's ability to deliver on contractual obligations;
  - CFO University will host at least 60 training events with more than 2,500 trainees reached; and
  - Continue executing the Agency's Strategic Workforce Plan to consolidate contracts while ensuring the right mix of civil servant and contractor support to enable the missions.

Customer Experience

Create and maintain a premium customer experience for NASA's mission directorates and Centers.

- Ensure ongoing engagement with customers to understand, integrate, and prioritize evolving customer needs and service requirements.
  - Award Agency Small Business Awards, which recognize outstanding support of the Agency Small Business Program;

MISSION ENABLING SERVICES

- Continue sharing NASA content and discoveries through various channels of communication, including the International Space Station, the Artemis Campaign, James Webb Space Telescope, and science missions;
- Conduct and host webinars and outreach events with internal collaboration and industry to provide training to SBs, contract specialist, technical personnel, and SBSs;
- Broadcast progress updates and mission milestones on the Artemis Campaign to increase knowledge among stakeholders and raise awareness outside of traditional audiences;
- Oversee NASA's advisory committees, commissions, and panels, and manage the Administrator-level NASA Advisory Council (NAC), NASA Aerospace Safety Advisory Panel (ASAP), and the International Space Station Advisory Council (ISSAC);
- Showcase the return of launching American astronauts to space from American soil on American-built spaceships using American rockets, highlighting the results and activities of the Commercial Crew program;
- Increase engagements with NASA's external stakeholders to build bipartisan support for the Administration's budget request and priorities for NASA, such as Artemis, climate change, STEM, and DEIA;
- Plan and implement sustained, strategic engagement with international partners in support of specific, growing requirements for NASA programs and as part of the design and development of the Agency's future exploration and Earth Science activities, through the establishment of new international agreements and managing over 600 active international agreements;
- Develop innovative arrangements with industry to promote and advance NASA's commercialization of LEO;
- Advance USG and NASA objectives through leadership of NASA/USG role in United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS);
- Support bilateral and multilateral engagement by NASA senior leaders to advance cooperative activities and establish and enhance relationships with international partners;
- Finalize with the SBA the Agency's SB goals for FY 2022 based on current and anticipated requirements; and
- Assist the SBA in its Small Business Program Surveillance Reviews at NASA centers.

- Promote diversity, inclusion, and engagement in the workforce and work environment reflective of NASA's core values.
  - Collaborate with Office of STEM Engagement to conduct and support the HBCUs/MSIs Technology Infusion Road Tour Initiative;
  - Established a quarterly meeting with SBA to discuss the 8(a) program, as it pertains to NASA activities;
  - Lead NASA's continued development and completion of deliverables required by Executive Orders and Presidential Memoranda on DEIA (including Executive Orders 13985, 13988, 14020, 14031, and 14035);
  - Enable innovative legal approaches to engage non-traditional communities that utilize and foster small business and increase accessibility to NASA resources;
  - Continue to provide essential support to the Agency EEO, anti-harassment, and reasonable accommodations processes;
  - Disposition over 1,000 requests for reasonable accommodations related to the COVID Vaccination requirements;
  - Lead the Agency-wide engagement and development of a new NASA DEIA Strategic Plan, as well as the development and implementation of new workforce DEIA data/analytics dashboard for all NASA centers and major organizations;

MISSION ENABLING SERVICES

  - Baseline the number of internship outreach activities/events for underrepresented and underserved students;
  - Issue Gender Transition Guidance;
  - Collect/analyze data and develop plans to brief OMB;
  - Continue support for targeted recruiting initiatives and tracking DEI Executive Orders to support more diversity and equity in job candidate pools and applicable Federal programs;
  - Develop a joint strategy for Agency internships by conducting a comprehensive analysis of the Intern Life Cycle to develop and implement the design of an impactful and integrated internship experience for participants and stakeholders;
  - Develop a white paper on the current state and future state envisioned for strengthening the pipeline for NASA employees in lower- or mid-level Center positions from underrepresented communities to progress to supervisory or leadership positions at Centers and headquarters. Include coaching and mentoring programs, professional development opportunities, and training for managers on how to support diversity in career staff advancement;
  - Create and execute a NASA DEIA Strategic Communications Plan;
  - Implement an enterprise-wide Sign Language Interpreter contract vehicle;
  - Reach and connect with under-represented communities through focused and deliberate STEM communications, outreach, and events;
  - Broadcast progress updates and mission milestones on the Artemis Campaign to increase knowledge among stakeholders and raise awareness outside of traditional audiences;
  - Engage underserved communities and improving equity in NASA’s administration of grants to external institutions that conduct STEM research (e.g., colleges and universities);
  - Identify opportunities to develop/improve diversity, equity, and inclusion; and
  - Engage underrepresented communities for hiring opportunities.

- Target, anticipate, and exceed customer needs using data.
  - Scale NASA's broadcasting and content sharing capabilities across the Agency to support the current, unprecedented launch cadence;
  - Use current and emerging tools to engage the public, with special focus on underserved populations, in the climate conversation and the societal impacts of NASA’s investment in climate research; and
  - Continue mission support-wide partnerships to develop current composition, metrics, and initiatives of our workforce.

Agility and Innovation

Create an environment of continuous transformation and stewardship resulting in more efficient and effective operations.

- Prioritize investment in projects that enhance, transform, and reduce costs of service delivery.
  - Find novel ways to share the value of NASA's exploration, science, and technology research with the American taxpayer.

- Utilize data-driven processes for prioritizing and integrating work, risk, resources, and decision making.
  - Continue health assessment, standardization, and evaluation of potential process improvements for additional financial core functions.

- Streamline services and shift from low-value to high-value work by eliminating unnecessary work, optimizing critical work, and automating wherever possible.

MISSION ENABLING SERVICES

- Engage ~500 subject matter experts within mission support to optimize and automate business services;
- Work collaboratively with internal budget and resource management business partners to optimize business services by identifying opportunities for automations through the Elimination, Optimization, Automation, and Digital Thrust Process Transformation working groups; and
- Utilize and leverage the new case and document management system, and other IT tools, that collectively comprise the NASA Legal Enterprise Operating System (LEOS) to prioritize and deploy legal services across the Agency.

- Create workspaces enabled with 21st century technology, virtual environments, and solutions that support distributed work teams and flexible work environments.
  - Maintain and expand the use of new and emerging communication tools to broadcast NASA content, including apps, digital and social media, television, on demand content and photojournalism.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

Service Delivery

Provide expert technical and professional services and capabilities to support NASA's missions.

- Protect and securely share NASA's critical data, information, and knowledge to enable mission success.
  - Securely share and utilize data, information, and knowledge with NASA stakeholders;
  - Share inspirational NASA content and mission milestones, including the International Space Station, the Artemis Campaign, James Webb Space Telescope, and science missions; and
  - Showcase the return of launching American astronauts to space from American soil on American-built spaceships using American rockets, highlighting the results and activities of the Commercial Crew program.

- Continuously improve NASA employee talent management to remain competitive for top talent and provide constant professional growth to the workforce.
  - Continue to execute our Strategic Workforce Plan to ensure NASA has the right procurement and acquisition specialist with the skills necessary to execute innovative, effective, and efficient acquisition business solutions;
  - Implement Agency Training Needs Assessments;
  - Continue current strategic acquisition strategy by awarding and phasing in all locations for the Regional Security Services contracts;
  - Continue to process the Agency Small Business Awards which recognizes outstanding support of the Agency Small Business Program for the Small Business Industry Awards, Small Business Advocates Awards, and Administrator's Cup;
  - Designed to find new small businesses and help the Agency increase its industrial base to support the NASA mission;
  - Prepare our acquisition professionals for all Federal Acquisition Certification in Contracting (FAC-C) level stages with necessary training and experience; and
  - Aggressively expand CFO University class offerings to reach more into the technical community and instruct them on the inner workings of the budget process.

Customer Experience

MISSION ENABLING SERVICES

Create and maintain a premium customer experience for NASA's mission directorates and Centers.

- Ensure ongoing engagement with customers to understand, integrate, and prioritize evolving customer needs and service requirements.
  - Develop, schedule, and host webinars, learning series, and podcasts with internal partners and industry collaborators to provide training to small businesses, contract specialists, technical personnel, and small business specialists;
  - Participate in global conversations around science, climate change, and green technologies;
  - Continue to support the development of innovative arrangements with industry to promote and advance the commercialization of low-Earth orbit (LEO);
  - Support small business outreach events;
  - Increase engagements with external stakeholders to advance NASA's 2022 Strategic Plan and build support for NASA priorities, such as Artemis, climate change, STEM, and DE&I;
  - Oversee NASA's advisory committees, commissions, and panels, and managing the Administrator-level NASA Advisory Council (NAC), NASA Aerospace Safety Advisory Panel (ASAP), and the International Space Station Advisory Council (ISSAC);
  - Complete the Small Business Administration (SBA) Scorecard evaluation assessment to assist the SBA in providing the Agency with its SBA Small Business Scorecard Grade;
  - Assist the SBA in its Small Business Program Surveillance Reviews at NASA centers;
  - Support bilateral and multilateral engagement opportunities for senior NASA officials to advance cooperative activities, establish and enhance relationships with international partners and other foreign officials, and conduct outreach activities; and
  - Establish new international agreements and manage NASA's over 600 active international agreements.

- Promote diversity, inclusion and engagement in the workforce and work environment reflective of NASA's core values.
  - Provide a minimum of $22 million for the Office of Diversity and Equal Opportunity, which includes NASA's diversity and equal opportunity enterprise efforts to prioritize advancing equity, civil rights, racial justice, and equal opportunity in accordance with NASA's Equity and DEIA Strategic Plans;
  - Update Executive performance requirements with DEIA requirements;
  - Ensure outreach events and engagement connect with audiences outside of NASA's traditional space community to include the underserved;
  - Lead NASA's implementation of Executive Orders and Presidential Memoranda on DEIA, including implementation and evaluation of NASA's DEIA strategic plan, as well as the enhancement of workforce data and analytics capabilities;
  - Expand professional development opportunities and training for managers to strengthen the pipeline for NASA employees in lower- or mid-level Center positions from underrepresented communities to progress to supervisory or leadership positions at the Centers and headquarters;
  - Develop additional partnerships or collaborations with other NASA organizations that increase the access and/or participation of MSIs in the work of the Agency;
  - Develop and implement a new NASA Procedural Requirements (NPR) on religious reasonable accommodations to maintain equity and inclusion;
  - Reach and connect with under-represented communities through focused and deliberate STEM communications, outreach, and events;
  - Continue to collaborate and partner with Office of STEM Engagement to conduct and support the HBCUs/MSIs Technology Infusion Road Tour Initiative;

MISSION ENABLING SERVICES

- Use new and modern communication technologies, platforms, and tactics to more effectively connect with underserved populations and improve accessibility to NASA work products and engagement opportunities;
- Enhance engagement, guidance, and oversight to grant recipient STEM institution community members, to enhance DEIA for nationally underserved communities and under-represented individuals in STEM; and
- Ensure underserved communities will have a fair opportunity to compete for NASA contracts at both the prime and subcontractor levels.

- Target, anticipate, and exceed customer needs using data.
  - Utilize empirical data, based on Key Performance Indicators, to validate procurement effectiveness and efficiency in enabling mission success; and
  - Improve operational metrics across the Enterprise, improving customer service to ensure we are meeting stated goals, objectives, and customer requirements.

Agility and Innovation

Create an environment of continuous transformation and stewardship resulting in more efficient and effective operations.

- Invest in projects that enhance, transform, and reduce costs of service delivery.
  - Continue investments in key communications technology, infrastructure, and talent to optimize broadcast reach and capability;
  - Develop international legal frameworks that will enable NASA's vision for lunar exploration and further commercialization of space; and
  - Migrate all centers to the three Enterprise acquisition contracts for finance, supporting our ability to provide more standard structure to providing services and potential cost savings/avoidance.

- Utilize data-driven processes for prioritizing and integrating work, risk, resources, and decision making.
  - Develop Enterprise data analytics platform to enhance access to real-time, integrated, and consistent data; and
  - Continue to collaborate across mission support to on PSLs, market research, and subcontracting training to all acquisition personnel.

- Streamline services and shift from low-value to high-value work by eliminating unnecessary work, optimizing critical work, and automating wherever possible.
  - Implement information technology enterprise applications to make it more streamlined and interactive, with the ability to provide increased data analytics to track usage and effectiveness;
  - Continue to explore new methods and technologies to share NASA's contribution to the American economy, including spinoff technologies, research, and national leadership;
  - Continue digital transformation to Human Capital Services while improving the service delivery model;
  - Achieve a 25 percent increase in financial process automations (BOTs, applications) to reduce the time spent on redundant, manual efforts and focus on high-value work; and
  - Expand use of templates, automated forms, and continue developing automated workflow processes to enable greater remote support and improved efficiency in the delivery of legal services.

- Create workspaces enabled with 21st century technology, virtual environments, and solutions that support distributed work teams and flexible work environments.

MISSION ENABLING SERVICES

- Enable the workforce with the skills, talent, and technology to ensure mission success in a post COVID environment;
- Enhance broadcast efforts with new and modern tools that engage more people, more effectively, in the United States and across the planet;
- Maintain NASA's standing as an Agency of inspiration by using new and emerging communication tools (apps, digital and social distribution, television and on demand, and photojournalism); and
- Expand and extend its digital transformation efforts in legal services to further enable remote client assistance and support.

Program Elements

OFFICE OF THE CHIEF FINANCIAL OFFICER

The Office of the Chief Financial Officer (OCFO) provides leadership for the performance reporting, budget analysis, justification, control, and reporting of all Agency fiscal resources; provides co-leadership for the strategic planning of all Agency fiscal resources; directly supports the development of the Agency's overarching strategic plan and associated annual performance reports; leads the Agency's planning, programming, budgeting, and execution process; oversees all financial management activities relating to the programs and operations of the Agency; and monitors and reports the financial execution of the Agency budget. Through supporting and fostering an agile workforce and enhancing robotic process automation, the OCFO continuously develops and matures modern toolsets, services, and processes for tracking, analyzing, and reporting mission and Agency financial information. The OCFO manages the Agency's budget and financial operations, directs the preparation and submission of annual financial and budgetary reports, and coordinates Agency financial management activities with other Federal agencies.

OFFICE OF CHIEF HUMAN CAPITAL OFFICER

The Office of the Chief Human Capital Officer (OCHCO) provides services and innovative solutions to ensure it meets the needs of our mission today and tomorrow. From creating a learning culture to implementing technology that supports work/life balance, OCHCO supports and strengthens the human foundation of NASA. Game-changing programs help Agency leaders understand workforce investments, anticipate workforce needs, and easily acquire talent for the task. Game-changing programs include streamlining and modernization of the Human Capital Information Technology (HCIT), simplification of position description (PD) classification, centralized training administration, implementing a flexible and agile workforce approach through the Strategic Workforce Plan (SWP), and replacing our aging talent acquisition system. NASA's talent needs are always evolving with mission activities that test the limits of human capability. Leaning forward to be a global leader in human capital excellence, OCHCO enables the people of NASA to push the boundaries of achievement by supporting NASA's mission first and its people always.

MISSION ENABLING SERVICES

OFFICE OF LEGISLATIVE AND INTERGOVERNMENTAL AFFAIRS

The Office of Legislative and Intergovernmental Affairs (OLIA) provides executive leadership, direction, and coordination of all communications and relationships, both legislative and non-legislative, between NASA and the United States Congress as well as state and local governments.

OFFICE OF PROCUREMENT

The Office of Procurement (OP) explores and executes innovative, effective, and efficient acquisition business solutions to optimize capabilities and operations that enable NASA's mission. NASA spends approximately 85 percent of its budget on acquiring goods and services through approximately 750 procurement and small business professionals across the Agency. In FY 2019, Agency spend was $19.7 billion via approximately 28,000 procurement actions (e.g., awards, modifications) while managing more than 23,000 instruments (e.g., contracts, purchase orders, task orders, and delivery orders). OP's transformed workforce, optimized capabilities, and continuous training opportunities keep it poised to deliver effective and efficient procurement services that ensure mission agility, resilience, and success.

OFFICE OF SMALL BUSINESS PROGRAMS

The Office of Small Business Programs (OSBP) promotes and integrates small businesses into NASA's industry base of competitive contractors that pioneer the future of space exploration, scientific discovery, and aeronautics research. OSBP provides integration, policy, initiatives, and oversight needed to ensure compliance with law and regulation to increase the Agency's small business industry base while offering the best technical solutions and value to support the Agency's mission. OSBP conducts, sponsors, and participates in small business outreach activities which assist small businesses, including small disadvantaged, women-owned, Historically Underutilized Business Zones (HUBZone), veteran-owned, service-disabled veteran-owned, and Historical Black Colleges and Universities (HBCU) / Minority Serving Institutions (MSI) in supporting the NASA mission.

OFFICE OF PROTECTIVE SERVICES

The Office of Protective Services (OPS) provides security services at all NASA facilities to ensure the protection of life and property across the Agency. OPS resources include a large contractor workforce in addition to its civil servant workforce. OPS provides secure access to intelligence and information essential to mission success, fire services, and emergency management at all NASA facilities and is the focal point for policy formulation, oversight, coordination, and management of Agency physical security, intelligence, counterintelligence, counterterrorism, emergency management, continuity of operations, fire services, national security, communications security (COMSEC), classified information security, personnel security, identity and credential management, electronic physical access management, insider threat, and protective services training programs. OPS provides services to ensure the safety and security of people, property, and information at 20 locations across the country.

OFFICE OF DIVERSITY AND EQUAL OPPORTUNITY

The Office of Diversity and Equal Opportunity (ODEO) leads diversity and civil rights policies, programs, and services, which enables the universe of available talent to contribute inclusively and

MISSION ENABLING SERVICES

equitably, propelling NASA organizations and people to work together more effectively to accomplish Agency missions. ODEO offers the best approaches to recruit, hire, engage, empower, and retain a highly talented workforce across a diverse landscape. ODEO programs empower and advance NASA as a leader and model Agency for diversity, equity, inclusion, and access, as well as promote external civil rights compliance in NASA-funded science, technology, engineering, mathematics, and other related programs.

OFFICE OF COMMUNICATIONS

The Office of Communications (OCOMM) delivers NASA's incredible work to billions of people around the world with compelling storytelling on a variety of platforms. NASA communicates via various methods including news and media engagement, digital services, and products (e.g., web, multimedia, social media), non-technical publications, exhibits, as well as speaking and public engagement activities and events, to promote effective and consistent NASA communications by ensuring strategic alignment and working collaboratively with other Agency organizations. OCOMM continues to manage NASA's astronaut appearances, guest operations, speakers' bureaus, exhibits, and artifacts. With NASA's new era in human spaceflight, OCOMM's work is critical to ensure NASA's advances in exploration, science, and discovery are shared with all communities.

OFFICE OF INTERNATIONAL AND INTERAGENCY RELATIONS

The Office of International and Interagency Relations (OIIR) provides executive leadership and coordination for all NASA international and interagency activities, and for policy interactions between NASA and other United States Executive Branch offices and agencies. OIIR manages the Agency's Export Control Program and Overseas Representation (France, Japan, and Russia), including compliance with Federally mandated requirements and all NASA and United States export and import laws, policies, and regulations, to maximize the benefits of the Agency's international efforts. OIIR provides Agency leadership for NASA overseas representatives who work with United States Embassies and senior foreign government officials in support of NASA's activities. OIIR travel resources are required to support the international travel of the NASA Administrator, Deputy Administrator, and other senior NASA officials in the cooperation of more than 700 active international agreements in over 125 countries as well as the NASA Advisory committees.

OFFICE OF THE GENERAL COUNSEL

The Office of the General Counsel (OGC) provides legal services Agency-wide, including establishing and disseminating legal policy and interpreting new statutes and cases to enable diverse and cutting-edge Agency activities, thus ensuring NASA remains in compliance with all statutory and regulatory requirements. Additionally, OGC is responsible for developing the ethics and patent program requirements, establishing metrics, and developing quality standards. As a functional office, OGC serves in an advisory capacity to the Administrator, Enterprise Associate Administrators, and Center Directors across nearly 20 core legal disciplines. OGC provides litigation expertise to the Agency and acts as the Agency representative before the United States Patent and Trademark Office and other administrative forums. NASA attorneys also function as leaders and trusted advisors on matters of policy and legal risk, upholding NASA values and enabling the NASA mission.

INFRASTRUCTURE & TECHNICAL CAPABILITIES

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**667.2**	**685.1**	**725.8**	**740.3**	**755.1**	**770.2**	**785.6**
Change from FY 2022 Budget Request			**40.7**				
Percent change from FY 2022 Budget Request			**5.9%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The aircraft management program supports the purchase of research and other aircraft, like the Gulfstream III, shown here with the SpaceX Crew-3 astronauts, ready to transfer from the Johnson Space Center in Houston to Kennedy Space Center in Cape Canaveral.

The NASA Infrastructure and Technical Capabilities (I&TC) program addresses Agency-wide operating requirements for physical assets considered institutional, and not fully funded by a single NASA mission directorate. The program maintains facilities, utilities, structures, and technical capabilities. It also provides oversight and management of real property assets, environmental program activities, aircraft operations, and logistics functions. Critical to supporting NASA's missions is the underlying infrastructure and skilled workforce that keep the centers and facilities operating effectively and efficiently.

I&TC Priorities

The I&TC program ensures NASA facilities have the research and engineering capabilities to sufficiently support mission activities. I&TC divides its allocation between failure prevention, in the form of routine preventative maintenance, and predictive testing, inspection, and other forward-looking investments in capabilities to support NASA's future missions.

The following goals and objectives align I&TC program functions with mission support and Agency priorities:

- Service Delivery: provide expert technical and professional support services and capabilities to NASA's missions.
  - Manage programs to ensure the health, safety, and security of NASA people, property, and the public while enabling mission success through technical excellence; and
  - Maintain and modernize NASA assets, including physical and IT infrastructures, to meet mission needs.
- Customer Experience: create and maintain a premium customer experience for NASA's mission directorates and centers.
  - Ensure ongoing engagement with customers to understand, integrate, and prioritize evolving customer needs and service requirements; and

- Target, anticipate, and exceed customer needs using data.

- Agility and Innovation: create an environment of continuous transformation and stewardship resulting in more efficient and effective operations.
    - Prioritize investment in projects that enhance, transform, and reduce costs of service delivery;
    - Utilize data-driven processes for prioritizing and integrating work, risk, resources, and decision making;
    - Streamline services and shift from low-value to high-value work by eliminating unnecessary work, optimizing critical work, and automating wherever possible; and
    - Create cyber-physical workspaces and solutions that support distributed work teams and flexible work environments.

EXPLANATION OF MAJOR CHANGES IN FY 2023

I&TC will increase support and content to meet NASA's commitment to environmental stewardship, as well as renewed commitment to ensuring physical assets are mission-ready, reliable, and safe. In 2023, I&TC funds will provide for (1) maintaining horizontal infrastructure (water, electrical, sewage, HVAC, etc.) across NASA's, with a focus on reducing the risk of arc flashes, a life-threatening phenomenon associated with antiquated electrical systems; (2) installing condition-based maintenance (CBM) technologies to enhance asset management and reduce costly failures and breakages; (3) modernizing the Arc Jet facility to reduce short-term risks and ensure unique capabilities are mission-ready to support work for thermal protection systems and high-heat, atmospheric re-entry for Artemis missions, International Space Station (ISS) crew and supply missions, Mars Sample Return, and others; (4) repurposing Space Environments Test chambers to address Agency requirements for lunar In-Situ Resource Utilization (ISRU) and surface excavation and activities and sustained human presence; (5) ensuring facility roofs are properly maintained, particularly at centers where damaging hurricanes and annual storms can potentially harm costly equipment and impact mission-critical systems and capabilities; and (6) addressing critical center investments needed to maintain laboratories, testing capabilities, equipment, and independent technical authorities.

ACHIEVEMENTS IN FY 2021

Service Delivery

Provided expert technical and professional support services and capabilities that sustained NASA's infrastructure, facilities, and physical assets to ensure mission success.

- Managed programs to ensure the health, safety, and security of NASA people, property, and the public while enabling mission success through technical excellence.
    - Initiated Arc-Flash mitigation projects at 6 centers to help eliminate safety risk due to over aged and non-compliant electrical infrastructure;
    - Provided critical ground testing capabilities to ensure mission success and maintain NASA's high standard of health and safety;
    - Conducted vertical motion simulations to develop scenarios and test cards in preparation for real, Advanced Air Mobility (AAM) flight tests with commercial collaborators;
    - Supported GRC's Vacuum Facility 5 to test long-duration performance and limitations of the Advanced Electric Propulsion System (AEPS) thruster for future large-scale, science missions and the transportation of cargo;

- Enabled NASA's space exploration and scientific research missions with 6,932 flight hours of safe aircraft operations;
- Implemented Commercial Aircraft Services (CAS) inspection program;
- Tested erosion and wear in the Vacuum Facility 5 to understanding long-duration performance and limitations of the Advanced Electric Propulsion System (AEPS) thruster for future large-scale, science missions, and the transportation of space cargo;
- Tested the Advanced NASA Evolutionary Xenon Thruster (NEXT) electronic propulsion thruster; and
- Reduced risk to mission and support NASA's commitment to the environment with comprehensive environmental compliance programing, including proactive agreements and permitting with State regulators and removal of potential compliance issues.

- Maintained and modernized NASA assets, including physical and IT infrastructures, to meet mission needs.
  - Sustained deteriorating or failed physical assets;
  - The Vertical Motion Simulator at ARC to supported tests by the Human Landing System (HLS) commercial collaborators and reduced landing risks as the vehicle design matures;
  - Refurbished JSC Vacuum Chambers A and B, including safety measures and fire suppression systems, which ensure human safety for Artemis lunar missions;
  - Supported the replacement of KSC's aging Huey II helicopters with new helicopters for space launch activities and Center operations;
  - Sustain deteriorating or failed physical assets based on mission relevancy, including chillers, air handlers, fire alarm panels, boilers, exhaust fans, roofs, roads, and various infrastructure system repairs;
  - Continued recapitalization of NASA's aircraft with LaRC's acquisition of an excess DoD Gulfstream G-IV aircraft and the disposition of the last operational S-3 aircraft at GRC; and
  - Completed the first work package as part of a multi-year program to restore and modernize the Arc Jet Complex.

Customer Experience

Created and maintained a premium customer experience to ensure NASA’s missions and Centers are supported with reliable infrastructure and capabilities when needed.

- Ensured ongoing engagement with customers to understand, integrate, and prioritize evolving customer needs and service requirements.
  - Continued Agency Master Plan (AMP) activities to understand the linkage between capabilities, facilities, and mission requirements by engaging with support customers.

- Targeted, anticipated, and exceeded customer needs using data.
  - Initiated over $6M in existing building retro-commissioning projects using Enhanced Use Lease (EUL) funds to create energy efficiencies and lower operating costs.

Agility and Innovation

Created an environment of continuous transformation and stewardship resulting in more efficient and effective operations throughout NASA’s facilities and infrastructure.

- Prioritized investment in projects that enhance, transform, and reduce costs of service delivery, including support for NASA’s commitment to environmental stewardship.

INFRASTRUCTURE & TECHNICAL CAPABILITIES

  - Avoided $27 million of cost due to agency-wide condition-based maintenance (CBM) measures, including $7 million in repair costs at GRC on a 16.5K HP altitude exhauster;
  - Continued investment in CBM measures in Space Environments Testing assets to include pressure, vibration, and temperature sensors on critical equipment to predict potential critical equipment failures;
  - Avoided $1.4 million in costs through a reliability-based bridge inspection process and new monitoring system at Kennedy Space Center (KSC);
  - Avoided $685,000 in costs with CBM by detecting issues with a 2,500-horsepower chiller motor at Goddard Space Flight Center (GSFC) by analyzing oil and vibrations;
  - Avoided $150,000 in costs through early detection of mechanical system anomalies at Langley Research Center (LaRC) that led to early replacement prior to failure;
  - Develop pre-emptive mitigation measures to reduce project cost and schedule impacts due to regulatory compliance activities;
  - Centralized National Environmental Protection Act (NEPA) process across all centers to streamline the decision-making process, reduce costs, and schedule impacts to future projects;
  - Implemented an Environmental Management Enterprise Strategic Plan to align Center environmental resources, providing efficiencies and standardize practices;
  - Improved sustainability practices, such as the Energy and Water Program Management Strategic Plan, to drive efficiency and cost savings across the Agency;
  - Reduced petroleum products usage and increased Alternative Fuel usage to 17 percent, meeting executive order metrics, and received OMB rating of Green; and
  - Developed an Agency Climate Action Plan in accordance with Executive Order 14008, Tackling the Climate Crisis at Home and Abroad, which integrates NASA’s climate change adaptation and climate resilience across Agency programs.

- Utilized data-driven processes for prioritizing and integrating work, risk, resources, and decision making.
  - Leveraged a logistical tool to screen top, mission-critical supplies of goods and services.

- Streamlined services and shifted from low-value to high-value work by eliminating unnecessary work, optimizing critical work, and automating wherever possible.
  - Assessed opportunities to install CBM technology to reduce administrative burden and incorporate cost saving practices into NASA's infrastructure maintenance program.

- Created workspaces enabled with 21st century technology, virtual environments, and solutions that support distributed work teams and flexible work environments.
  - Supported the transition of workspaces to hybrid spaces as the Agency as the Agency tailored operations during the COVID-19 pandemic.

WORK IN PROGRESS IN FY 2022

Service Delivery

Provide expert technical and professional support services and capabilities that sustain NASA’s infrastructure, facilities, and physical assets to ensure mission success.

- Manage programs to ensure the health, safety, and security of NASA people, property, and the public while enabling mission success through technical excellence.

  - Establish Aircraft Capability Management Office (ACMO) in the Mission Support Directorate to actively pursue the recapitalization of aging aircraft assets;
  - Continue to reduce arc flash and layered pressure vessel system risk through ongoing mitigation and testing;
  - Test wear and erosion for the Advanced Electric Propulsion System (AEPS) thruster in the GRC Vacuum Facility 5 for future, large-scale, science missions and cargo transportation;
  - Support Advance Air Mobility (AAM) industry development with vertical motion simulations to develop scenarios and test cards in preparation for real flight test; and
  - Reduce risk to mission and support NASA's commitment to the environment with comprehensive environmental compliance programing, including proactive agreements and permitting with state regulators and removal of potential compliance issues.

- Maintain and modernize NASA assets, including physical and IT infrastructures, to meet mission needs.
  - Continue modernization of ARC's Arc Jet Complex, a critical Agency ground testing capability used for flight qualified thermal protection systems for atmospheric entry;
  - Refurbish JSC's Vacuum Chambers A and B with upgrades for safety, data collection, and unique capabilities to support Exploration Extravehicular Mobility Unit Design Verification Test (xEMU DVT) activities;
  - Continue investment in CBM measures in Space Environments Testing assets to include pressure, vibration, and temperature sensors on critical equipment to predict potential critical equipment failures;
  - Re-purposing and testing in space environments chambers to address Agency requirements for a soil simulation capability to enable the development of lunar and planetary landing, exploration, and excavation systems;
  - Support the acquisition of a Pilatus PC-12 at GRC to replace the 50-year-old Twin Otter aircraft; and
  - Support the replacement of the increasingly unsustainable Super Guppy aircraft with a newer aircraft.

Customer Experience

Create and maintain a premium customer experience to ensure NASA's missions and Centers are supported with reliable infrastructure and capabilities when needed.

- Ensure ongoing engagement with customers to understand, integrate, and prioritize evolving customer needs and service requirements.
  - Continue AMP activities to identify the linkage between capability, facility, and mission requirement through engagements with customers;
  - Integrate all facilities and asset data gathered from Centers to generate the first draft of the Agency Master Plan that better prioritizes asset investments and activities based on mission requirements;
  - Advance commercial space activities by supporting separation and launch testing for Blue Origin and Sierra Nevada;
  - Implement an Environmental Management Enterprise Strategic Plan to align Center environmental resources, providing efficiencies and standardize practices; and
  - Develop an integrated approach to supply, store, analyze, and provide geospatial data and technical support to NASA's stakeholders, including DoD, industry, and other agencies.

INFRASTRUCTURE & TECHNICAL CAPABILITIES

Agility and Innovation

Create an environment of continuous transformation and stewardship resulting in more efficient and effective operations throughout NASA's facilities and infrastructure.

- Prioritize investment in projects that enhance, transform, and reduce costs of service delivery, including support for NASA's commitment to environmental stewardship.
  - Reduce costs associated with the International Space Station by utilizing the Defense Contract Management Agency to performed Property Management System reports (PMSA, which recently avoided $4.5 million of cost);
  - Create NASA's first Agency-wide Capital Investment Program Plan (CIPP) to prioritize and identify phased projects tied to the Agency Master Plan;
  - Improve sustainability practices, such as the Energy and Water Program Management Strategic Plan, to drive efficiency and cost savings across the Agency;
  - Implement an Environmental Management Enterprise Strategic Plan to align Center environmental resources, providing efficiencies and standardize practices; and
  - Transition to a Zero Emission Vehicle (ZEV) fleet by installing the necessary recharging infrastructure and establishing acquisition criteria to begin replacing NASA's fuel-powered fleet of 2,609 vehicles with electrical vehicles.
- Utilize data-driven processes for prioritizing and integrating work, risk, resources, and decision making.
  - Continue installation of key technologies for condition-based maintenance on critical equipment and facilities to prevent failures and reduce operational maintenance costs; and
  - Begin procurement of an enterprise-level, computerized maintenance management system/enterprise asset management software system to advance the Agency Maintenance program.
- Streamline services and shift from low-value to high-value work by eliminating unnecessary work, optimizing critical work, and automating wherever possible.
  - Begin piloting tiered maintenance approach at four centers to address routine and backlogged maintenance through the prioritization of risk to mission-critical assets based on available funding and mission priorities;
  - Continue transformation to improve strategic coordination, resource allocation, and agile management of NASA's physical asset portfolio, including real-property and facilities;
  - Continue transformation to improve strategic coordination, resource allocation, and agile management of NASA's Space Environments Testing asset portfolio; and
  - Provide NEPA coverage for all centers to streamline the decision-making process, reduce costs, and schedule impacts to future projects.
- Create workspaces enabled with 21st century technology, virtual environments, and solutions that support distributed work teams and flexible work environments.
  - Provide critical upgrades and maintenance to the flight simulators at ARC and LaRC to provide human-and-hardware-in-the-loop flight simulation capabilities for aerospace research Configure rooms and ensuring the hybrid workforce is accommodated to optimize efficient work.

INFRASTRUCTURE & TECHNICAL CAPABILITIES

KEY ACHIEVEMENTS PLANNED FOR FY 2023

Service Delivery

Provide expert technical and professional support services and capabilities that sustain NASA's infrastructure, facilities, and physical assets to ensure mission success.

- Manage programs to ensure the health, safety, and security of NASA people, property, and the public while enabling mission success through technical excellence.
  - Reduce arc flash and layered pressure vessel system risk through ongoing mitigation, inspection, and testing;
  - Continue testing in space environments chambers to address Agency requirements for a soil simulation capability to enable the development of lunar and planetary landing, exploration, and excavation systems; and
  - Reduce risk to mission and support NASA's commitment to the environment with comprehensive environmental compliance programing, including proactive agreements and permitting with State regulators and removal of potential compliance issues.
- Maintain and modernize NASA assets, including physical and IT infrastructures, to meet mission needs.
  - Continue modernization of the Arc Jet Complex, a critical Agency ground testing capability used for flight qualified thermal protection systems for atmospheric entry;
  - Actively pursue aircraft recapitalization for assets essential to NASA's missions, such as the DC-8 science platform and high-performance F-15 and F-18 support aircraft; and
  - Continue investment in condition-based maintenance (CBM) measures across all centers to include pressure, vibration, and temperature sensors on critical equipment to predict potential critical equipment failures.

Customer Experience

Create and maintain a premium customer experience to ensure NASA's missions and Centers are supported with reliable infrastructure and capabilities when needed.

- Ensure ongoing engagement with customers to understand, integrate, and prioritize evolving customer needs and service requirements.
  - Realize NASA's first AMP prioritize execution of needed investments and divestments across the Agency;
  - Brief the final Agency Master Plan to leadership and implement across the agency; and
  - Support commercial space activities through the separation and launch testing for SpaceX.
- Target, anticipate, and exceed customer needs using data.
  - Reduce the administrative costs of implementing Real Estate agreements through the implementation of the REAMs enterprise tool, while increasing the efficiency and effectiveness.

Agility and Innovation

Create an environment of continuous transformation and stewardship resulting in more efficient and effective operations throughout NASA's facilities and infrastructure.

- Prioritize investment in projects that enhance, transform, and reduce costs of service delivery, including support for NASA's commitment to environmental stewardship.

INFRASTRUCTURE & TECHNICAL CAPABILITIES

  - Implement NASA’s five-year plan to transition to Zero Emission Vehicle (ZEV) Federal fleet, including conversion of gas-powered fleet, site-level planning tools, and training content;
  - Finalize the Agency-wide Capital Investment Program Plan (CIPP) to prioritize the investment strategy, based on the AMP;
  - Implement an Environmental Management Enterprise Strategic Plan to align Center environmental resources, providing efficiencies and standardize practices;
  - Implement Enterprise organization that will enable 10 percent reduction in CS workforce by 2027;
  - Reduce risk to mission and support NASA's commitment to the environment with comprehensive environmental compliance programing, including proactive agreements and permitting with State regulators and removal of potential compliance issues; and
  - Improve sustainability practices, such as the Energy and Water Program Management Strategic Plan, to drive efficiency and cost savings across the Agency.

- Utilize data-driven processes for prioritizing and integrating work, risk, resources, and decision making.
  - Develop a centralized database of assets that identifies mission relevance and future state for use by both mission and institutional managers and stakeholders;
  - Use data analytics from condition-based maintenance to predict failures, ensure operational readiness, reduce maintenance costs, and use energy monitoring to drive toward efficient operations; and
  - Create supply chain climate resiliency models and analysis in support of climate action planning in collaboration with the NASA Aeronautics Research Institute.

- Streamline services and shift from low-value to high-value work by eliminating unnecessary work, optimizing critical work, and automating wherever possible.
  - Continue transformation to improve strategic coordination, resource allocation, and agile management of NASA's technical capabilities;
  - Provide NEPA coverage for all centers to streamline the decision-making process, reduce costs, and schedule impacts to future projects; and
  - Establishing a centralized procurement for geospatial support and consolidating the enterprise architecture into a centrally managed solution.

- Create workspaces enabled with 21st century technology, virtual environments, and solutions that support distributed work teams and flexible work environments.
  - Maintain and upgrade the unique X Flight simulators at ARC and LaRC to provide real-time, high fidelity, full mission flight simulation capabilities to conduct preeminent aerospace research.

Program Elements

AIRCRAFT MANAGEMENT

The Aircraft Management Program provides capability leadership, oversight, and coordination of NASA’s aviation assets, including Uncrewed Aircraft Systems to enable NASA’s missions in science, technology, aeronautics, and space exploration. NASA policy sets the highest standards and best practices of aviation safety. Program-Independent Flight Operations Offices provide oversight of Center aircraft flight operations and ensure aircraft operations can meet unique missions worldwide in a safe manner. These offices include a Chief of Flight Operations, an Aviation Safety Officer, a Chief of Maintenance,

INFRASTRUCTURE & TECHNICAL CAPABILITIES

and a Chief of Quality Assurance to ensure oversight of qualified personnel operating aircraft that are airworthy and mission ready.

ENVIRONMENTAL MANAGEMENT

The Environmental Management Program encompasses the development, implementation, and oversight of Agency policies for environmental planning, compliance, restoration, pollution prevention, energy and water conservation, and sustainability while preserving natural, cultural, and historic resources in balance with enabling the NASA missions. The program enables compliance with applicable Federal, State, and local environmental laws and regulations, as well as NASA policy in day-to-day operations and mission support. Specifically, Environmental Management covers NASA's programs for local environmental policy development, Environmental Management System (EMS) implementation, environmental permitting and compliance, recycling, sustainable acquisition, hazardous materials and waste management, pollution prevention, energy and water management systems and reporting, renewable energy, natural resources, historic properties, and National Environmental Policy Act (NEPA) program support.

FACILITIES SERVICES

The Facilities Services program encompasses the institutional facilities support activities throughout the Agency. The budget supports utilities, operations and maintenance, real estate, and facilities engineering to include civil construction designers, engineers, and project managers. I&TC funds the civil servants and procurements that operate and manage NASA's institutional infrastructure. NASA recently deployed a cost model that forecasts the funding requirements to sustain its inventory of facilities at the current condition. NASA manages a portfolio of assets with over $2.8 billion in deferred maintenance. The I&TC budget supports a strategy to reduce the growth of backlogged maintenance and systematically improve the reliability of NASA institutional infrastructure from transformers and substations to buildings, horizontal infrastructure, and test capabilities.

LOGISTICS MANAGEMENT

The Logistics Management program encompasses the development, implementation, and management of Agency-wide logistics policies, processes, services, system innovation, and facilitates the implementation of Government and industry best practices for NASA's centers and facilities. Logistics Management provides functional management, oversight, and coordination over the Agency's personal property equipment, supply and material, warehouse and receiving operations, property disposal, and artifact property disposition. The program also provides oversight for contractor-held property management, mail and freight management, transportation management, life cycle logistics and supply chain management, policy compliance and logistics contracts, and Agency library management. Logistics Management ensures the readiness of material and equipment for NASA's scientific, aeronautics, and space exploration mission requirements at 10 NASA centers and three component facilities. The program includes receiving and inspecting supplies/materials as well as issuing and moving those materials so that products critical to NASA's space exploration mission arrive at the desired locations in an efficient manner.

INFRASTRUCTURE & TECHNICAL CAPABILITIES

TECHNICAL CAPABILITIES MANAGEMENT

The Space Environments Testing Management Office provides the centralized and strategic management of a portfolio of specific capabilities to enable NASA's missions in science, technology, aeronautics, and space exploration. Examples of these capabilities are provided below:

- The high-enthalpy test capability at ARC's Arc Jet Complex provides simulated high-temperature, high-velocity environments and supports the design, development, test, and evaluation of Thermal Protection Surface (TPS) materials, vehicle structures, aerothermodynamics, and hypersonic aerodynamics experienced by a vehicle during planetary atmospheric entry.
- Flight simulators are of critical importance to NASA's research in fundamental aeronautics and aviation safety. These capabilities provide scientists and engineers with tools to explore, define, and resolve issues in vehicle design and mission operations. The capabilities include the motion simulators and development laboratories used in the research and development of flight and crewed operations at the ARC Vertical Motion Simulator and the LaRC Flight Simulation Facility.
- Space environments testing capabilities and facilities whose primary use is related to spacecraft and instrument development and qualification, space technology development, human-rated space environments, and launch environments. Capability components include vacuum, thermal/vacuum, and thermal chambers; vibration tables; acoustic labs; cleanrooms; and electromagnetic interference and electromagnetic compatibility, magnetic, optical, X-ray, solar spectrum, and ionizing radiation facilities. Located at most NASA centers, testing performed with these capabilities ensures the equipment, sub-systems, and assembled spacecraft will survive the harsh noise and vibrations experienced during launch and the ultra-low pressure and ultra-low or ultra-high temperatures experienced in space environments.
- The external radiation testing capability procures the necessary time and facility support at non-NASA facilities to meet the requirements of Agency programs and projects. The test facilities provide controlled sources of electrons, heavy ions, neutrons, protons, and other relevant types of high-energy radiation that NASA uses to simulate the impact of the natural space radiation environment on a wide range of electronic and material systems. National laboratories, private companies, and universities at both domestic and foreign locations operate these highly specialized facilities. Test activities support a wide range of assessment, development, and flight activities.

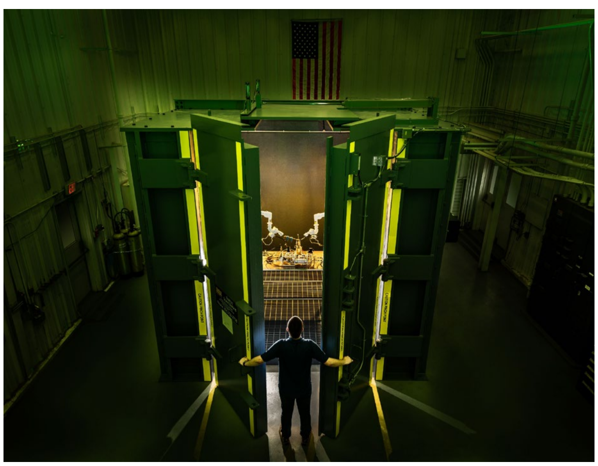
ENGINEERING, SAFETY, & OPERATIONS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Agency Technical Authority	182.8	186.8	**195.1**	199.0	203.0	207.0	211.2
Center Engineering, Safety, & Operations	835.4	833.7	**859.2**	876.4	893.9	911.8	930.1
Total Budget	**1,018.2**	**1,020.4**	**1,054.3**	**1,075.4**	**1,096.9**	**1,118.9**	**1,141.3**
Change from FY 2022 Budget Request			**33.9**				
Percent change from FY 2022 Budget Request			**3.3%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



Shown here, a test engineer checks test equipment in the Boom Box High Pressure Test Enclosure in Building 353H at Johnson Space Center. Independent testing is a vital part of part of technical authority oversight and

Engineering, Safety, and Operations (ESO) supports NASA's high standard of safety and mission assurance, while maintaining center flexibilities that promote innovation and mission success. ESO is divided between two, distinct programs: Agency Technical Authority (ATA) and Center Engineering, Safety, and Operations (CESO).

ATA protects the overall health and safety of NASA's workforce and programs by providing technical oversight for safety, health, quality, and engineer. The independence of ATA offices is a vital part of NASA's checks and balances to ensure safety, quality, and engineering concerns are always vetted, analyzed, and mitigated. ATA offices develop policies, guidance, and conduct reviews at a corporate level, which are implemented at the center-level through CESO programs.

CESO provides funding for several center-level activities, including the operations and management at nine centers and component facilities, in addition to corporate leadership at NASA Headquarters (HQ), the execution of delegated technical authority at the centers, and center investments to ensure mission success, innovation, and technical excellence. CESO allows centers the flexibility to address mission-critical requirements, such as acquiring specialized scientific and engineering equipment. CESO funds center-level implementation of ATA policies and guidelines and preserves the checks and balances at each center that ensure the highest standards of health, safety, and mission assurance. It also supports NASA's competitive bid and proposal process. CESO includes center institutional operations that are not performed by NASA's enterprise functional offices. CESO encompasses a diverse set of ongoing activities and unique projects in support of center operations and infrastructure, while enabling safe and effective mission support.

ENGINEERING, SAFETY, & OPERATIONS

ESO Priorities

ESO is aligned to key objectives under the Agency and mission support strategy to deliver high-quality and affordable services to centers and missions. ESO contributes to the safe and successful exploration of space, development of aerospace research and technology, and pursuit of scientific breakthroughs. Management goals and objectives include:

- Service Delivery: provide expert technical and professional support services and capabilities to NASA's missions.
    - Manage programs to ensure the health, safety, and security of NASA people, property, and the public while enabling mission success through technical excellence; and
    - Securely share and utilize data, information, and knowledge with NASA stakeholders.
- Customer Experience: create and maintain a premium customer experience for NASA's mission directorates and centers.
    - Ensure ongoing engagement with customers to understand, integrate, and prioritize evolving customer needs and service requirements; and
    - Target, anticipate, and exceed customer needs using data.
- Agility and Innovation: create an environment of continuous transformation and stewardship resulting in more efficient and effective operations.
    - Utilize data-driven processes for prioritizing and integrating work, risk, resources, and decision making; and
    - Streamline services and shift from low-value to high-value work by eliminating unnecessary work, optimizing critical work, and automating wherever possible.

ESO provides the critical funding that aligns center activities to corporate standards and mission priorities, while providing centers the agility and adaptability to support innovation and mission work. ESO is a diverse portfolio that provides for a range of activities in corporate leadership, center investment, technical authority management and implementation, and policy development and guidance for engineering, health, and safety:

- Provide independent review and technical oversight for health, safety, and mission assurance, including medical and engineering evaluations;
- Provide policy, guidance, and oversight to ensure optimal outcomes for health, safety, bioethics in research;
- Evaluate risks of potential loss of life, engineering issues, health impacts, and mission failure;
- Provide policy, oversight, and validation of highly technical equipment, facilities, and laboratories to meet NASA's standards for quality, reliability, and safety;
- Sustain NASA's engineering and research capabilities with support services, like analysis, testing, and fabrication, as well as independent research, development projects, and equipment purchases; and
- Support corporate leadership at NASA HQ, the operationalization of Agency policies, business innovation, and effective and efficient mission work.

EXPLANATION OF MAJOR CHANGES IN FY 2023

See each program area for a description of significant changes.

ENGINEERING, SAFETY, & OPERATIONS

ACHIEVEMENTS IN FY 2021

See each program area for a complete list of achievements in FY 2021 for ATA and CESO.

WORK IN PROGRESS IN FY 2022

See each program area for a complete list of work in progress in FY 2022 for ATA and CESO.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

See each program area for a complete list of planned achievements in FY 2023 for ATA and CESO.

Programs

AGENCY TECHNICAL AUTHORITY (ATA)

ATA work is managed by the Offices of the Chief Health and Medical Officer (OCHMO), Safety and Mission Assurance (OSMA), and the Chief Engineer (OCE), and includes vital programs like the NASA Safety Center (NSC), the Independent Verification and Validation (IV&V), and the NASA Engineering and Safety Center (NESC). These activities provide the foundation for NASA's system of checks and balances, defined in NASA's Strategic Management and Governance Handbook, by providing for the technical authority over health, safety, and engineering, independent of the missions. Through independent analysis and deep subject matter expertise, ATA develops policy, designs procedural requirements, and provides recommendations to NASA's Administrator, mission directorates, center directors, and program managers, who are ultimately responsible for the safety and mission success of all NASA activities.

ATA provides training and maintains a competent technical workforce with expertise in system engineering, system safety, reliability, quality, and space medicine. Subject matter experts analyze risks and risk acceptability through an established process of independent reviews and assessments. The information and advice from these experts provide critical data required to develop authoritative decisions related to the application of requirements on programs and projects.

CENTER ENGINEERING, SAFETY, AND OPERATIONS (CESO)

NASA's Center Engineering, Safety, and Operations (CESO) is a multifaceted program that ensures Agency leadership is implemented at the center-level, while centers have the flexibility and support to ensure mission success and uphold NASA's high standard of safety and engineering excellence.

CESO ensures NASA's unique, technical, and innovative capabilities are mission-ready by supporting center-level institutional and technical capabilities through independent research, development projects, and maintenance of facilities, laboratories, and other mission-critical assets. The technical skill and specialized assets or services that support analyses, design, research, testing, laboratories, and fabrication enable the efficient and effective implementation of mission work at the centers, now and in the future. CESO funds are used by centers to ensure the technical skills and capabilities are available and mission-ready based on mission requirements and timelines.

ENGINEERING, SAFETY, & OPERATIONS

CESO is a key component of NASA's overall approach to risk management by providing center-level independent technical authority. By funding center-level oversight and reporting activities that uphold the strategy and guidance from ATAs, checks on safety, engineering, and mission assurance remain separate from mission directorates.

CESO funds NASA HQ operations, as well as center management, across the Agency. Support for institutional administration and operational safety are vital to allow centers the flexibility to address and manage conditions unique and specialized to their center. CESO also ensures that Agency policies and guidance are operationalized across centers with consistency and efficiency.

AGENCY TECHNICAL AUTHORITY

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**182.8**	**186.8**	**195.1**	**199.0**	**203.0**	**207.0**	**211.2**
Change from FY 2022 Budget Request			**8.3**				
Percent change from FY 2022 Budget Request			**4.4%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Employees at Michoud Assembly Facility (MAF), shown above, continue vital mission work while abiding my COVID protocols. Their continued onsite work is made possible by clear guidance and the Agency framework provided by the Office of the Chief Health & Medical Officer (OCHMO).

Agency Technical Authority (ATA) programs protect the health and safety of the NASA workforce by evaluating programs, projects, and operations to ensure safe and successful completion. ATA capabilities provide expert technical excellence, mission assurance, and technical authority Agency-wide.

ATA work is managed by the Offices of the Chief Health and Medical Officer (OCHMO), Safety and Mission Assurance (OSMA), and Chief Engineer (OCE), and includes vital programs like the NASA Safety Center (NSC), the Independent Verification and Validation (IV&V), and the NASA Engineering and Safety Center (NESC). These activities provide the foundation for NASA's system of checks and balances, defined in NASA's Strategic Management and Governance Handbook. Through independent analysis and deep subject matter expertise, ATA develops policy, designs procedural requirements, and provides recommendations to NASA's Administrator, mission directorates, center directors, and program managers, who are ultimately responsible for the safety and mission success of all NASA activities.

ATA provides training and maintains a competent technical workforce with expertise in system engineering, system safety, reliability, quality, and space medicine. Subject matter experts analyze risks and risk acceptability through an established process of independent reviews and assessments. The information and advice from these experts provide critical data required to develop authoritative decisions related to the application of requirements on programs and projects.

ATA Priorities

ATA is vital to ensure the safe and healthy advancement of space exploration, technological advancement, and scientific discoveries. All ATA activities support mission support's primary goal of health and safety for both the NASA workforce and the public. Within that primary goal, ATA is focused on critical objectives that support mission safety, heath, and ethics:

AGENCY TECHNICAL AUTHORITY

- Provide independent review and deep technical knowledge on health and safety, including medical and engineering evaluations, across all mission activities;
- Ensure ethical conduct in NASA's research and experimentation activities;
- Evaluate risks to mission, including the potential loss of life, engineering failures, health impacts, and mission failure; and
- Provide policy and technical guidance to ensure optimal mission health, safety, and success.

EXPLANATION OF MAJOR CHANGES IN FY 2023

To align with NASA's priorities, ATA will increase content and service under the Health and Medical Technical Authority (HMTA). Funds requested in FY 2023 will increase labor and provide special equipment to ensure HMTA has the personnel and equipment needed to support human landing systems, system integration with the lunar gateway projects, and the lunar terrain vehicle development.

ACHIEVEMENTS IN FY 2021

- Provided vital health and medical expertise across the Agency, including reviews, independent evaluations, policy development, and general guidance:
  - Continued to enhance and provide health and medical expertise to NASA's priority missions;
  - Provided technical requirements for human spaceflight standards; and
  - Supported mission activities with Human Systems Integration (HSI).
- Provided technical oversight, independent reviews, and evaluations of mission work to ensure safety and success:
  - Identified 100 Severity 1 and 2 software issues which, if manifested in operations, have the potential to result in the loss of mission or the loss of an essential mission capability;
  - Supported the successful Space-X Crew 1 & 2, Landsat-9, and Lucy launches in addition to a successful Mars 2020 landing;
  - Provided independent software & cyber security evaluation and verification for numerous NASA mission areas;
  - Issued a standard defining procedures to establish OSHA-compliant safety bases for the continued use of multi-layered and other pressure vessels in NASA's inventory that pre-date the establishment of consensus codes;
  - Conducted the Boeing CCP Organizational Safety Assessment;
  - Supported multiple academic, industrial, and interagency collaborations to increase the utilization of commercial off the shelf (COTS) microelectronics in aerospace applications with respect to quality, reliability, and radiation survivability;
  - Updated NASA's orbital debris mitigation requirements making them fully consistent with the United States Government Orbital Debris Mitigation Standard Practices;
  - Updated NASA's directive on Planetary Protection Provisions for Robotic Extraterrestrial Missions (NPR 8715.24). This update clarified the planetary protection requirements consistent with COSPAR guidelines, aligned planetary protection implementation and verification with standard project management and systems engineering practices; and
  - Updated NASA's nuclear flight safety processes for launching space nuclear systems, consistent with new United States Government policy. This update, to be published as a separate directive, clarifies, and streamlined process for launching radioactive sources, and simplifies the launch authorization process.

AGENCY TECHNICAL AUTHORITY

- Provided technical review and expertise of engineering specifications and activities across the Agency:
    - Engineering Technical Authority supported the Agency's most important programs, ensuring independent technical insight and assessment of these programs at key programmatic milestones, such as: X-57; X-59; ISS; CCP; Artemis; Gateway; and James Webb Space Telescope;
    - Conducted over 70 independent assessments of NASA's highest risk and highest priority mission work;
    - Completed the Pilot Breathing Assessment that determined root cause for breathing difficulties experienced by pilots who fly the Nation's highest performance aircraft;
    - Conducted testing to anchor Linear Elastic Fracture Mechanics analyses used to analyze life of composite overwrapped pressure vessels, which fly on all crewed spacecraft and most satellite missions in NASA and DoD. Also completed hypervelocity impact testing of COPVs to reduce modeling uncertainty for a given mission orbital profile;
    - Completed investigations into fire safety equipment on Commercial Crew Provider spacecraft and occupant protection for nominal and off-nominal returns from ISS;
    - Completed major efforts to increase safety of high-power Lithium-ion batteries used on ISS and on all crewed spacecraft and supported updated purity analysis procedures of hypergolic propellant constituents that must now be procured from outside of the United States;
    - Supported failure analysis for the National Science Foundation's investigation into the collapse of the Arecibo Observatory;
    - Completed final review and closeout of Space Network Ground Segment Sustainment (SGSS) project, and transition to SCaN's Space Relay project for deployment; and
    - Conducted review and assessment of commercialization approach to low-Earth orbit space mission communications and navigation solutions from emerging industries.

WORK IN PROGRESS IN FY 2022

- Continue to enhance and provide health and medical expertise to NASA's priority missions:
    - Continue to enhance and provide health and medical expertise to NASA's priority missions;
    - Provide technical requirements for human spaceflight standards; and
    - Support mission activities with Human Systems Integration (HSI).

- Support the ongoing safety and mission assurance activities that prevent loss of life and mission failures through independent evaluations and deep technical expertise:
    - Expand the cybersecurity assessment capability to find software vulnerabilities in NASA's orbital assets;
    - Provide independent verification and validation of critical mission software;
    - Preparing for the successful launch of JWST in December 2021;
    - Integrate center and Agency activities performed to assess the health of institutional safety, including Agency audits, self-evaluations, center assessments, and identification of systemic safety risks;
    - Continue development and evaluation of innovative approaches to planetary protection including metagenomics for biological contamination assessment and analysis tool development to efficiently quantify spacecraft bioburden for the benefit of mission providers;
    - NASA is updating its policy and procedures for evaluating and deciding whether to expose NASA or NASA sponsored crew on a given space system and mission, to account for the new space systems, process, and acquisition models; and

AGENCY TECHNICAL AUTHORITY

  - Enhance and sustain key activities, including new radar data on debris populations optical surveys, in-situ measurement sensors, and orbital debris shape modeling to monitor the ever-changing orbital debris environment.

- Provide and enhance critical engineering expertise, guidance, and oversight for mission activities:
  - Collaborate with other ATAs to enhance the Agency's ability to provide technical reviews, guidance, and support to missions;
  - Develop employee resources to provide technical guidance and policy for consistent application of Engineering Technical Authority (ETA) services across centers;
  - Ensure employees and reviewers can voice dissenting opinions or raise concerns regarding safety concerns;
  - Provide engineering guidance, oversight, and review through the NESC to all NASA missions, with priority focus on astronaut spaceflight (commercial and otherwise), ISS maintenance, space exploration activities, and science missions;
  - Examine, maintain, and improve discipline-specific capabilities needed to support current and future NASA mission development and operations;
  - Support of upgrades of the Space Communications and Navigation (SCaN) network for deep space missions;
  - Develop commercialization plan of low-Earth orbit and lunar relay communications and navigation service; and
  - Continue to support the Agency's most important programs, ensuring independent technical insight and assessment of these programs at key programmatic milestones, such as: X-57; X-59; ISS; CCP; Artemis; Gateway; and James Webb Space Telescope.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

- Continue to enhance and provide health and medical expertise to NASA's priority missions:
  - Continue to enhance and provide health and medical expertise to Agency's portfolio of development and operations; and
  - Continue to develop relationships with commercial space providers as well as other Federal agencies (e.g., Space Force, NIH).

- Support the ongoing safety and mission assurance activities that prevent loss of life and mission failures through independent evaluations and deep technical expertise:
  - Provide independent testing and evaluation for NASA missions, including simulations, studies, verification, and validation;
  - Prepare for the successful launch of Psyche in FY 2023;
  - Provide baseline policy, oversight, training, and support functions, along with anticipated policy updates related to mission safety and assurance;
  - Develop and provide specialized training in support of aerospace microelectronics and radiation effects workforce development;
  - Establish a new capability to assess and build relationships with high-volume industry-leading microelectronics manufacturers that supports the increased utilization of COTS devices in high-reliability aerospace applications;
  - Provide technical guidance and oversight of planetary protection as technical requirements are developed and hardware is designed for human missions to Earth’s Moon and capability is further developed for future human missions to Mars;

AGENCY TECHNICAL AUTHORITY

- Develop, maintain, and improve orbital debris environment models, tools, and algorithms to improve orbit predictions, understand spacecraft anomalies, and better interpret sensor data;
- Invest in space and ground-based sensors to better detect and characterize space objects with increased perceptivity, better resolution, and reduced uncertainty;
- Lead the development of and update to orbital debris mitigation standards, measures, and policies with the United States, partnering with DoD and other agencies, and internationally through forums and committees;
- Work with interagency partners and private industry to share best practices for coordinating in-orbit activity to ensure a safe and sustainable orbital environment; and
- Upgrade NASA's SMA workforce development to ensure the talent needed to successfully design, develop, operate, and oversee the many varied future missions and the new technologies and engineering and oversight processes.

- Provide and enhance critical engineering expertise, guidance, and oversight for mission activities:
  - Continue collaborations with other ATAs to enhance the Agency's ability to provide technical reviews, guidance, and support to missions;
  - Ensure employees and reviewers can voice dissenting opinions or raise concerns regarding safety concerns;
  - Develop lunar communications and navigation relay capabilities, in line with Agency's LunaNet architecture, for future science and crewed Artemis missions;
  - Continue provision of engineering guidance, oversight, and review through the NESC to all NASA missions, with priority focus on astronaut spaceflight (commercial and otherwise), ISS maintenance, space exploration activities, and science missions;
  - Examine, maintain, and improve discipline-specific talent needed to support current and future NASA mission development and operations;
  - Continue support of Commercial Crew launches, ISS sustainment, Artemis missions, and science missions; and
  - Advance development and implementation of cross-Agency training for the technical workforce to enhance program and project management and systems engineering skills.

Program Elements

OFFICE OF THE CHIEF HEALTH AND MEDICAL OFFICER (OCHMO)

OCHMO promulgates Agency health and medical policies and standards to support the medical technical capabilities of NASA. As a functional area, OCHMO provides independent oversight and advances expert health and medical capabilities from development through de-commissioning. It assures the physical and mental health and well-being of the NASA workforce.

OCHMO also ensures that bioethics principles and NASA's policies and practices related to the use of human and animal subjects in research are in accordance with all relevant Federal regulations and guidelines. The program oversees NASA's processes for reviewing the use of human and animal subjects in research.

OCHMO administers HMTA, which engages in all crewed programs. The HMTA provides guidance, insight, and oversight, while translating health and medical standards into tailored technical requirements for all Human-Rated programs across the Agency. HMTA ensures that integrated spaceflight systems

AGENCY TECHNICAL AUTHORITY

reflect the most current knowledge on health and medical impacts related to flight, life support, and environmental systems.

OFFICE OF SAFETY AND MISSION ASSURANCE (OSMA)

OSMA assures the safety and enhances the success of all NASA activities through the development, implementation, and oversight of Agency-wide safety, reliability, maintainability, and quality assurance policies and procedures. OSMA establishes and maintains an acceptable level of technical excellence and competence in safety, reliability, maintainability, and quality engineering areas. The program assesses and communicates risk associated with noncompliance and/or compliance with safety requirements to appropriate decision makers.

OSMA conducts a schedule of reviews and assessments that focuses on the life cycle decision milestones for crucial NASA programs and projects, safety, reliability, and quality processes. Embodied in this program is a structured development of methodology and investigation into system attributes that improve the probability of mission success.

OSMA includes the Mission Support Division, Safety and Assurance Requirements Division, and NASA Safety Center, as well as the Independent Verification and Validation Facility (IV&V).

The NSC, an OSMA component, consolidates safety and mission assurance activities for affordable and consistent service across the Agency. It supports general technical excellence, knowledge management, audits and assessments, and mishap investigation support. NSC helps protect the safety of people, equipment, and property by verifying compliance with OSMA policies and works proactively to prevent mishaps and failures.

The IV&V program ensures that mission critical systems and software will operate reliably, safely, and securely. It provides independent oversight and technical knowledge across NASA missions. IV&V is funded through the SSMS account with additional support from mission directorates.

OFFICE OF THE CHIEF ENGINEER (OCE)

OCE ensures that NASA's development efforts and mission operations are planned and conducted with sound engineering practices, proper controls, and management of technical risks. The program provides independent engineering oversight and guidance to ensure that decisions have the benefit of different points of view and are not made in isolation.

OCE ensures that NASA's development efforts and mission operations are planned and conducted on sound engineering principles with proper controls and management of technical risks. Further, OCE establishes and maintains program/project management and engineering policy and technical standards. Additionally, OCE creates the foundation for excellence of program/project management and engineering workforce, system-engineering methodology, and system of engineering standards throughout the Agency.

OCE also sponsors the Academy of Program/Project and Engineering Leadership Knowledge Services (APPEL KS) to develop program and project management and systems engineering skills and support critical knowledge sharing across the Agency's technical workforce. APPEL provides a formal professional development curriculum designed to address four career levels spanning from recent college graduate to executive.

AGENCY TECHNICAL AUTHORITY

OCE manages the NESC, which enables rapid, cross-Agency responses to mission critical engineering and safety issues at NASA and improves the state of practice in critical engineering disciplines. Established in FY 2003 in response to the recommendations of the Space Shuttle Columbia Accident Investigation Board, the NESC performs independent testing, analysis, and assessments of NASA's high-risk projects to ensure safety and mission success. As an Agency-wide resource with a reporting path that is independent of the mission directorates and directly funded from OCE, the NESC helps the Agency ensure mission safety and obtain objective technical results.

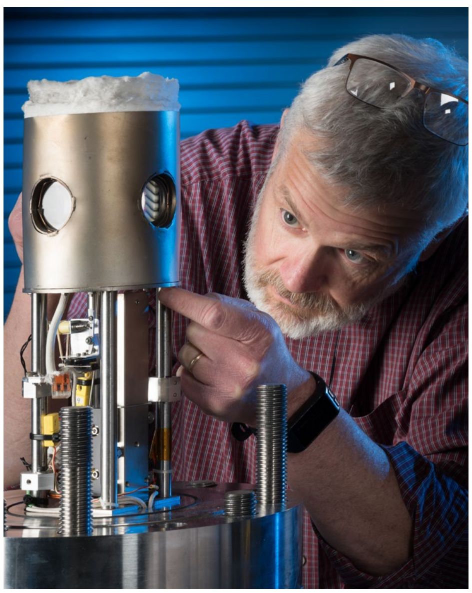
CENTER ENGINEERING, SAFETY, & OPERATIONS

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**835.4**	**833.7**	**859.2**	**876.4**	**893.9**	**911.8**	**930.1**
Change from FY 2022 Budget Request			**25.5**				
Percent change from FY 2022 Budget Request			**3.1%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



Shown here, an engineer conducts a High Pressure Microgravity Combustion Experiment to study the ignition process in engine conditions, made possible by unique Center equipment and laboratory capabilities at Glenn Research Center (GRC).

NASA's Center Engineering, Safety, and Operations (CESO) program provides strategic management and crucial policy direction at the Agency- and center-level in addition to center-level technical authority and capabilities that ensure mission success.

CESO maintains test capabilities, laboratories, and other mission critical assets so they are available and mission-ready based on mission requirements and timelines. The technical skill and specialized assets or services that support analyses, design, research, testing, laboratories, and fabrication enable the efficient and effective implementation of mission work at the centers.

CESO programs contribute to NASA's overall approach to risk management by providing center-level independent technical authority. By funding center-level oversight and reporting activities that uphold the strategy and guidance from Agency Technical Authorities (ATAs), checks on safety, engineering, and mission assurance remain separate from mission directorates.

CESO funds Headquarters (HQ) operations, as well as center management across the Agency. This institutional support for center operations and infrastructure allows the centers to focus on managing conditions unique to their center. CESO also ensures that Agency policies and guidance are operationalized across the centers with consistency and efficiency.

CESO Priorities

CESO activities maintain the necessary technical skills and capabilities at each center, driven by mission requirements, while ensuring alignment and implementation of Agency-level policies and standards. CESO funds critical activities that maintain NASA standards for safety and engineering excellence and catalyzes technical innovation and unique capabilities. CESO priorities support the Agency and centers in their responsibility to meet mission requirements and include:

CENTER ENGINEERING, SAFETY, & OPERATIONS

- Ensure laboratories, critical capabilities, and associated specialized equipment are mission-ready and meet NASA's standards for quality, reliability, and safety;
- Sustain the engineering and research capabilities in analytical support, test services, lab services, and fabrication capabilities that are unique and specific to each center;
- Apply delegated technical authorities to ensure the highest standards of quality and safety in engineering and mission assurance;
- Fund independent research and development projects that ensure centers have mission-ready technical capabilities and capacity to support NASA's missions (now and in the future);
- Support management activities at the center-level, including the operationalization of Agency policies and guidance across institutional and functional areas; and
- Support Agency-level operations at NASA HQ to ensure the development and implementation of Agency-wide policies, standards, and processes are effective and efficient.

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

ACHIEVEMENTS IN FY 2021

- Supported the unique scientific and engineering capabilities at each center by funding specialized equipment, services, and other costs associated with laboratories and facilities:
  - Conducted several virtual town halls and workshops at science conferences (AGU, ACS, ASGSR, ISSR&D) to communicate NASA's mission to the public and provide a venue to discuss facility/lab capabilities;
  - The Mars Transportation Architecture Study was performed in 2021. Nuclear Thermal Propulsion technology enables closure for the 2039 Opposition mission;
  - Completed outfitting of the new Research Support Building (RSB) to provide office and collaboration space for 164 NASA employees/contractors, a multiyear effort to revitalize GRC's central campus and renovate/replace WWII era buildings;
  - Began outfitting of the new Aerospace Communication Facility (ACF), to include award of special test equipment—the ACF will comprise research and development laboratories specialized in design and construction for NASA's communication technologies;
  - Continued to invest in high and low voltage electrical repairs and replacement of transformers to address a Class A Mishap, including acceptance and installation of the J6 high voltage transformer;
  - Combined with the Rocket Propulsion Test (RPT) Program, upgraded WSTF's liquid and gaseous nitrogen recharging system;
  - Purchased a Scanning Electron Microscope for detailed failure analysis of EEE Parts for the Agency which will improve overall uptime, reduce job delays, is capable of 1 million times zoom, and can handle the highest complexity failure analyses and inspections;
  - Installed a state-of-the-art computerized numerical control vertical turning and milling machine enabling fabrication of hardware with highly defined, complex geometries and extremely tight tolerances as needed for NASA's Exploration Extravehicular Mobility Unit Program; and

CENTER ENGINEERING, SAFETY, & OPERATIONS

- Consolidated LaRC's Unmanned Aerial Systems (UAS) labs which enabled the UAS development-to-test cycle to be completed at one location which increased efficiency and reduced handling risks which has directly supported ARMD's Integrated Aeronautics Systems Program's (IASP), Advanced Air Mobility (AAM) Project, and the Transformative Aeronautics Concepts Program's (TACP) Transformational Tools and Technologies (TTT) Project.

- Invested in collaborative research activities, key infrastructure, and NASA's competitive bidding process to ensure centers are innovative and capable of supporting missions, today and in the future:
  - Anticipated independent studies through NAS and universities to help with finalizing NASA's Artemis Campaign;
  - IRAD supported three Science B&P efforts; two SCMD sponsored Phase A efforts; three short term technology investments; and managed 54 Cooperative Agreements with external entities to include 10 small businesses and 12 Minority University Research and Education Project (MUREP) partners;
  - Invested in the development of advanced technology that drives future missions while also bidding and proposing for new work; and
  - Developed and transferred revolutionary technologies, the transformation of aviation, and to inspire and engage the public in exploration and science mission projects.

- Ensured operational safety through the maintenance, repair, or replacement of equipment and facilities, or the management of hazardous or potentially hazardous conditions and materials:
  - Industrial Safety continued support of various projects, to include SLS, with testing and transport of hardware; implemented Process Safety Management at MSFC; and performed building inspections and mishap investigations for life safety code compliance;
  - Invested in Fluids and Propellant Infrastructure to replace 30-year-old hardware that was limiting support capabilities to the SLS and KSC partners, providing new mechanisms for reliable propellant and high-pressure gas delivery;
  - Paid for the KSC West Causeway Utility Line Relocate, enabling the replacement of the aged Indian River Bridge and allowing Center access to continue unabated during the new bridge's construction activities;
  - Accept and activate two new propellant tanker vehicles, thereby significantly decreasing the previous risk to reliable and timely delivery of propellant services to NASA-KSC Mission and Center partners;
  - Transitioned centers through the stages of NASA's COVID Response Framework, which created consistency and safety across centers while ensuring the continued productivity on critical mission work;
  - Conducted two very successful on-site COVID vaccination events resulting in the vaccination of 725 NASA ARC civil servants and contractors;
  - Continued to provide Employee Assistance Program (EAP) services across the Agency to support employees through the unprecedented conditions of the global pandemic;
  - Provided occupational health onsite to ensure continued productivity on mission critical operations while protecting employee health and complying with guidelines; and
  - Responded to unprecedented challenges and evolving mission requirements with minimal loss or risk to Agency priorities as we continue to operate under COVID-19 conditions with safety and health being a high priority.

- Supported the independent, technical authority at the center-level that ensures NASA's high standard for health and safety, engineering excellence, and mission assurance:

CENTER ENGINEERING, SAFETY, & OPERATIONS

- Continued efforts to certify MSFC laboratory pressure systems. Of the approximately 130 MSFC laboratories, 100 percent have been inspected and approximately 28 percent are now certified;
- Provided Technical Authority and System Safety, Reliability the successful Core Stage 1 Green Run, Artemis I/SLS hardware delivery, stacking and launch of the Integrated Core Stage Boosters;
- Funded renewal and enhancement of Engineering and Science capabilities, replacing old testing and evaluation hardware that directly supports Mission goals, including a new Vehicle Motion Simulator, and acquiring an X-ray Photoelectron Spectrometer;
- Supported the Agency strategic objective of assuring safety and mission success through guidance and oversight of Center operations, infrastructure, and personnel;
- Supported the Science Mission Directorate's Airborne Science missions with technical oversight and guidance;
- Supported the Global Hawk SkyRange reimbursable project through management of requirements, technical reviews, and oversight;
- Performed Certification of Flight Readiness for the BioSentinel mission. Led by the Ames Office of Chief Engineer, a team of engineering subject matter experts assessed the residual risk in the as-built spacecraft in preparation for integration as a secondary payload on the first Space Launch System launch;
- Helped Center Operations Directorate and NASA Research Park apply risk management principles and the Project Controls Integration (PCI) tool suite to make decisions regarding infrastructure (property and facilities);
- Achieved Initial Operational Capability of the Gulfstream III aircraft (NASA 520) with a configuration that includes two nadir research portals, avionics interfaces, and accommodations for up to 10 researchers enabling research to better understand how emissions impact climate;
- Incorporated LaRC's City Environment Range Testing for Autonomous Integrated Navigation (CERTAIN) test range into a Smart City Digital Operations environment and demonstrated a potential solution to mitigate radio frequency impact on unmanned aircraft systems (UAS) operation safety which is currently being used by the Aeronautics System Wide Safety Project;
- Enabled Space Launch System (SLS) development by executing 7 RS-25 engine tests and provided the required scope of test data to the program;
- Ensured B-2 Test Stand supported the SLS Core Stage program schedule, including the safe completion of two Green Run Tests, post-test operations, and removal of the Core Stage for shipment to KSC;
- Met safety, engineering, and environmental requirements specified in Space Act Agreements, enabled test services for reimbursable customers and delivered scope of test data to meet corporate, NASA, and national defense propulsion goals and objectives;
- Supported institutional administration and Center administration, which includes leadership priorities and business innovations through process improvement and technologies;
- Served on multiple working groups and definition teams in support of the Artemis Campaign and other Agency priorities;
- Represented NASA on four subcommittees of the OSTP Joint Committee on the Research Environment;
- Led the NASA Web Modernization Team to revitalize NASA’s internet presence;
- Released the new science integrity training course into NASA's training database (SATERN);
- Completed the transition to enterprise management and service delivery, which has strengthened the technical capabilities and expertise that support mission-critical work;

CENTER ENGINEERING, SAFETY, & OPERATIONS

- Enabled Future of Work concept of operations evaluations, analyses, and piloting to best prepare the KSC to posture itself towards fully and successfully meeting the needs of a dynamically situated workforce in the post-pandemic setting;
- Started the Project Management Community of Practice at ARC, providing a knowledge sharing forum for project managers to learn best practices and increase their Project Management expertise;
- Created an Ames Inclusion Champion role at the Center to be an advisor to both the staff and management; and
- Created a virtual tool (Project Access Selection System - PASS) that supervisors used to request on-site access as part of return to work (RTOW). The system allowed the Office of Director to control the pace of on-site work which resulted in a very low COVID-19 case count and no on-Center transmission.

WORK IN PROGRESS IN FY 2022

- Support the unique scientific and engineering capabilities at each center by funding specialized equipment, services, and other costs associated with laboratories and facilities:
  - MSFC Metrology and Calibration Laboratory (MCL) will continue to support calibrations, function tests, adjustments/alignments, repairs, and other support events for MSFC with focus on meeting test schedule dates for SLS, ISS, and others;
  - Complete the Aerospace Communications Facility (ACF) construction and outfitting; the ACF will comprise several research and development laboratories that specialize in design and construction for NASA's communication technologies;
  - Pursue additional necessary investments in KSC's Fluids and Propellant Infrastructure to replace aged and end-of-life hardware, thus ensuring reliable delivery of propellant and high-pressure gas services to resident program and Center partners;
  - Evaluate existing KSC Engineering and Sciences hardware and capabilities for renewal and enhancement opportunities to ensure reliable, cost-effective delivery of services to KSC program and customers;
  - Purchase Pulsed Laser Radiation Test System for radiation testing of Electrical, Electronic, and Electro-mechanical (EEE) parts that will increase efficiency and eliminate the need to use costly out-of-house solutions;
  - Procure new WSTF Scanning Electron Microscope (SEM) will provide valuable capability used to gather data for multiple test customers (propulsion, materials, technical services, S&MA, environmental, and reimbursable entities);
  - Develop a new, reconfigurable universal data acquisition system (DAS) to increase efficiency, reduce time-to-flight, and reduce cost across the lifecycle of Unmanned Aerial Systems (UAS) projects, such as the Integrated Aeronautics Systems Program's (IASP) Advanced Air Mobility (AAM) project and the Transformative Aeronautics Concepts Program's (TACP) Transformational Tools and Technologies (TTT) project;
  - In support of future Science missions (e.g., Earth System Observatory/Atmosphere Observing System Program), upgrade LaRC's 8x15 Thermal Vacuum Chamber ground support equipment to a platen system to improve safety and mitigate undesirable shock loads during transition into the chamber while also increasing the overall payload mass capability that can be tested in the chamber; and
  - Complete design, fabrication, and installation of final phase of Baseline Research System in Gulfstream III aircraft for ACTIVATE, multiple upper-level wind test, and Artemis.

CENTER ENGINEERING, SAFETY, & OPERATIONS

- Invest in collaborative research activities, key infrastructure, and NASA's competitive bidding process to ensure centers are innovative and capable of supporting missions today and in the future:
  - Continue studies supporting Agency priorities such as lunar sustainability and Planetary Protection;
  - Conduct a Citizen Science project in support of the Artemis Campaign;
  - In cooperation with NASA History Office, document histories for the great astronomical observatories, Discovery program missions, and other topics;
  - Work with industry to leverage the technology through Space Act Agreements and Broad Agency Announcements to support the MC2 Prototype Engine;
  - Execute an Interagency Agreement between the United States Space Force and NASA related to common interests in Launch Vehicle and Propulsion Systems analytical and test capabilities;
  - Support the successful efforts to bring a major private-sector satellite manufacturing plant to KSC, thereby growing the Center's multi-user spaceport posture and helping to advance United States preeminence in space industry;
  - Continue efforts to identify and advocate for reimbursable projects that advance the Nation and Agency's objectives of engaging collaborators and transforming aviation; and
  - Invest in the development of advanced technology that drive future missions while also bidding and proposing for new work.
- Ensure operational safety through the maintenance, repair, or replacement of equipment and facilities, or the management of hazardous or potentially hazardous conditions and materials:
  - Obligate funding for nondestructive examination equipment, machine additional layered vessels, and recertify all systems and vessels which become uncertified in FY 2022;
  - Continue to address pandemic issues and requirements to ensure Center personnel working in a safe environment;
  - Continue to address issues and requirements to ensure Center personnel working in a safe environment; and
  - Develop health and COVID-19 safety protocols to provide services to on-site employees in order to work effectively as part of return-to-work activities.
- Support the independent, technical authority at the center-level that ensures NASA's high standard for health and safety, engineering excellence, and mission assurance:
  - Support to Artemis I verification, waiver adjudication and other technical support to readiness and launch;
  - Continue risk mitigation of high voltage systems and subsystems, to include acceptance and installation of J4/J5 high voltage transformers;
  - Continue to support the Agency strategic objective of assuring safety and mission success through support and oversight of Center operations, infrastructure, and personnel;
  - Continue to provide independent discipline and engineering leadership and oversight to the Center's projects in aeronautics, science, space technology, and exploration;
  - Continue to support the NAVAIR F-18 Loads Calibration reimbursable project that is expected to be completed in 2022;
  - Continue to support the Global Hawk SkyRange reimbursable project;
  - Support Science Mission Directorate Airborne Science program DC8 and C-20 aircraft foreign deployment requirements;
  - Support Science Mission Directorate SOFIA program foreign deployment requirements;
  - Begin testing of failover/COOP capabilities allowing for engineering (design, test, fabrication, and analysis) to continue during weather and pandemic events;

CENTER ENGINEERING, SAFETY, & OPERATIONS

  - Lead the VIPER Lunar Rover Mission Safety and Mission Assurance Team through a successful Critical Design Review (CDR);
  - Provide technical support and testing for the Arc Jet Complex and Vertical Motion Simulator, which are unique simulation and testing capabilities critical for Artemis mission;
  - Continue to provide program/project Safety and Mission Assurance Technical Authority (TA) and support NASA mission success;
  - Conduct pressure systems recertification inspections at the National Transonic Facility (NTF) and Transonic Dynamics Tunnel (TDT) to ensure safe and reliable operations and ensure FY 2022-planned mission program/project tests remain on schedule. Planned tests include Orion MPCV Heat Shield Roughness Evaluation (ESDMD), Tail Cone Thruster I (ARMD), Mars Sample Return - Earth Entry System Forced Oscillation Test (SMD), Dragonfly Aeroshell Capsule Test (SMD), SLS Multi-Configuration Rigid Buffet Test (ESDMD), and Blue Origin Dynamic Stability Test; and
  - Ensure B-2 Test Stand supports the SLS Exploration Upper Stage (EUS) program schedule, including the continued design and buildout of Special Test Equipment required to test the upper stage element upon its arrival in 2024.

- Support institutional administration and Center administration, which includes leadership priorities and business innovations through process improvement and technologies.
  - Lead Agency efforts to ensure continued scientific rigor and integrity;
  - Support the Science Mission Directorate’s efforts to refine career path opportunities for Agency scientists in terms of recruitment, onboarding, training, diversity & inclusion, and retention;
  - Continue to lead NASA Web Modernization Team to revitalize NASA’s internet presence;
  - Transition toward a future hybrid work model, including investment in conference room upgrades to enable hybrid meetings and implementation of a six-to-nine-month hybrid pilot program in 2022;
  - Using a risk Management approach, we continue building a viability support foundation capable of ensuring exploration, science, technological advancement, and leadership;
  - Continued to transform operations and technology to increase effectiveness, optimize efficiencies, and mature the enterprise model for a more agile and responsive support services;
  - To address a significant KSC risk, CESO is investing in the setup of a local configuration management (CM) capability. Current activities include performing Center-wide configuration audits, creation of a CM program office, and modernizing CM tools;
  - Maintain the Center's Management System, Configuration Management support, Audits & Assessments, Program/Project Review Support, GIDEP, Metrology and Calibration, In-house Software Assurance Assessment and Electrostatic Discharge programs;
  - Develop investment strategy for lunar surveying, Mars exploration, returned sample analysis, solar/Earth weather detection, as well as a continued search for habitable planets; and
  - Conduct analyses, including environmental scans, to recognize long-term trends and use in conjunction with NASA's mission priorities to identify the best strategic positioning for LaRC to serve the Agency.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

- Support the unique scientific and engineering capabilities at each center by funding specialized equipment, services, and other costs associated with laboratories and facilities:

CENTER ENGINEERING, SAFETY, & OPERATIONS

  - Install Aerospace Communications Facility (ACF) Special Test Equipment; this is a partnered initiative, jointly funded by CESO, ARMD, and HEO, that will enable enhanced research and development for NASA's communication technologies;
  - Make critical strategic investments in laboratories, technical equipment, and facilities aligned with Agency goals and objectives;
  - Upgrade 31 critical electrical systems that support JSC's facilities that house collections lunar, meteorite, cosmic dust, Genesis, Stardust, Hayabusa and Mars 2020 contamination knowledge mission samples; and
  - Continue to invest in Smart Center which is needed for digital accessibility through support of LaRC's Center-wide, small unmanned aerial vehicle (UAV) test range (City Environment for Range Testing of Autonomous Integrated Navigation [CERTAIN]) and by expansion of services like internet of things (IoT) and 5G (fast and high bandwidth) wireless.

- Invest in collaborative research activities, key infrastructure, and NASA's competitive bidding process to ensure centers are innovative and capable of supporting missions, today and in the future:
  - In cooperation with NASA History Office, document histories for NASA astronaut training, planetary and astronomical missions, and other topics;
  - Continue leading NASA's citizen science program;
  - Work with industry to leverage the technology through Space Act Agreements and Broad Agency Announcements for the MC2 Prototype Engine;
  - National Institutes for Rocket Propulsion Systems (NIRPS) will continue to support efforts to maintain and advance United States leadership in all aspects of rocket propulsion for defense, civil, and commercial uses;
  - Enhance key technical capabilities and expertise that are mission-critical for Agency priorities, including returning to the Moon, creating a lunar gateway, launching the James Webb Telescope, and catalyzing economic development in aerospace, aeronautics, science, and technology;
  - Launch a new program for identifying strategic opportunities with external Federal labs. Develop more than 25 new strategic relationships and 20 new patent license agreements;
  - Generate targeted responses to the Agency's requests for new work covering mission and instrument activities in all four science divisions as one of only two NASA-designated science Centers;
  - Provide competitively selected "seed funding" opportunities to our civil servant workforce to develop concepts, develop technological capabilities, and provide leadership opportunities with the broader scientific community; and
  - Focus on increased Tenant Occupancy and collaboration with industry for additional opportunities.

- Ensure operational safety through the maintenance, repair, or replacement of equipment and facilities, or the management of hazardous or potentially hazardous conditions and materials:
  - Support the Agency strategic objective of assuring safety and mission success through support and oversight of Center operations, infrastructure, and personnel;
  - Ensure that the Center personnel are provided all critical medical services to ensure compliance with Government and Agency mandates, in support of mission support strategic objectives, and mission requirements;
  - Continue to address issues and requirements to ensure Center personnel working in a safe environment; and
  - Continue to ensure the health and safety of all staff during the ongoing COVID-19 pandemic.

CENTER ENGINEERING, SAFETY, & OPERATIONS

- Support the independent, technical authority at the center-level that ensures NASA's high standard for health and safety, engineering excellence, and mission assurance:
  - Continue to provide program/project Safety and Mission Assurance Technical Authority (TA) and support NASA mission success;
  - Perform load testing and associated nondestructive testing (NDT) on all lifting devices and equipment in Attachment J-10, "Lifting Devices," of the FOMSS contract in accordance with NASA-STD-8719.9;
  - Support technical reviews and Flight Readiness Reviews for the Aeronautics Research Mission Directorate (ARMD) X-57 and X-59 flight research project;
  - Provide Technical Authority and Quality/Safety center-level support to Artemis II and subsequent SLS Hardware delivery for the Integrated Core State Boosters and in support DDT&E for Exploration Upper State and Booster Obsolescence Life Extension hardware;
  - Provide independent technical reviews and Flight Readiness Reviews for the Aeronautics Research Mission Directorate (ARMD) flight research projects;
  - Provide independent discipline and engineering leadership and oversight to the Center's projects in aeronautics, science, space technology and exploration;
  - Support Science Mission Directorate Airborne Science program DC8 and C-20 aircraft foreign deployment requirements with technical oversight;
  - Support Science Mission Directorate SOFIA program foreign deployment requirements;
  - Support Technical reviews and Flight Readiness Reviews for the Aeronautics Research Mission Directorate (ARMD) X-57 flight research project;
  - Provide technical support and testing for the Arc Jet Complex and Vertical Motion Simulator, which are unique simulation and testing capabilities critical for Artemis mission;
  - Support LaRC's City Environment Range Testing for Autonomous Integrated Navigation (CERTAIN) test range into a Smart City Digital Operations environment by demonstrating a potential solution to mitigating radio frequency impact on unmanned aircraft systems (UAS) operation safety which is currently being used by the Aeronautics System Wide Safety project;
  - Operate the Geometry Laboratory (GEOLAB) to ensure continued technical excellence in numerical geometry and mesh generation which will be utilized by projects such as Hypersonic Technology, Low Boom Flight Demonstrator (LBFD), and X-57;
  - Recertify four major institutional high-pressure distribution systems, as part of the Langley Pressure Systems 15-Year Recertification Plan, that are essential for providing heating and cooling for most NASA LaRC buildings. Additionally, will recertify 16-meter thermal vac chamber utilized for key Agency structural and materials research;
  - Provide Metrology and Calibration Program Standard Practice and Metrology Quality Assurance which is necessary to obtain accurate and precise measurement data for NASA's research and development experimental efforts; and
  - Enable the Agency's SSC mission of rocket propulsion testing to support the Artemis Campaign; SSC is in the critical path for SLS/Artemis success with RS-25 and Enhanced Upper Stage (EUS) test programs.

- Support institutional administration and Center administration, which includes leadership priorities and business innovations through process improvement and technologies:
  - Lead Agency efforts to ensure continued success in space exploration, technology, aeronautics, and science mission related activities;
  - Lead updates of NASA Science Integrity Policy. Continue supporting interagency working groups on research integrity and security;
  - Support Agency efforts for post-COVID-19 Future of Work and Return to Onsite Work;

CENTER ENGINEERING, SAFETY, & OPERATIONS

- Lead outreach and engagement events for NASA communication activities;
- Implement Intelligent Global Search (IGS) capability across MSFC technical data archives; continue development of collaborative digital environments through Model-Based Design and Manufacturing Tools operations;
- Engage stakeholders and customers to build coalition, deepen the catalyzing impact of NASA's achievements, and serve the American public with inspirational content;
- Deepen mission support capabilities by investing in enterprise tools and processes that will improve effectiveness and efficiency and empower the agile support of NASA's evolving mission requirement;
- Support Future of Work implementation through initiatives fostering innovative and collaborative office settings, including the modification and outfitting of shared-use spaces and conference facilities necessary to successfully enable reliable and seamless concurrent communication and activity between on and off-site participants;
- Utilize our mature risk process to identify/mitigate/communicate risks throughout the year effecting our portfolio;
- Enable small businesses to collaborate with NASA in delivering technological innovations;
- Foster regional alliances with organizations to advance the commercialization of UAS and smaller, lower-cost scientific payloads; and
- Promote licensing of NASA-developed technologies in fields such as Non-Destructive Evaluation, Autonomous Systems, Acoustics, Composites and Coatings, Sensors and Actuators, Advanced Materials, and Space Structures.

Program Elements

AGENCY SUPPORT AND HEADQUARTERS MANAGEMENT

CESO supports Agency-level strategic leadership and planning by funding corporate activities conducted at NASA HQ. Strategic planning, budget activities, workforce management, and other foundation business functions require strategic planning, policy development, monitoring, audits, and ongoing management. These activities dovetail with center operations through mission support functional offices and senior management. CESO funds also ensure there is enterprise-enabling support for centers and missions, in functional areas not aligned to a mission support enterprise office (which would then be funded through Mission Services and Capabilities).

INSTITUTIONAL ADMINISTRATION

CESO supports certain foundation business functions at the center-level by funding center management, center reserves, and certain unique functions that were not transitioned to enterprise management due to their unique value or specification at the Center. Activities, deemed center-centric, remained under center management to ensure location-specific conditions and decisions were considered when supporting mission requirements. These center-level activities include occupational health, local IT support, and local management personnel.

CENTER ENGINEERING, SAFETY, & OPERATIONS

INSTITUTIONAL OPERATIONAL SAFETY

CESO funds safety and mission success requirements based upon Federal regulations and NASA standards, ensuring these requirements are properly implemented throughout NASA's programs and projects. Examples of such efforts include safety audits and assessments, safety surveillance, inspections, testing and observations, mishap investigation and reporting, hazard identification, and safety outreach.

SAFETY AND MISSION ASSURANCE (SMA) TECHNICAL AUTHORITY

The Office of Safety and Mission Assurance (OSMA) issues policies, guidance, and corporately managed communications that ensure the consistent application of safety and quality standards. At each center, Safety and Mission Assurance (SMA) personnel are responsible for the application and implementation of policies and instructions provided by OSMA and related governing organizations. This is accomplished through SMA Technical Authority (TA) member participation on program/project control boards, change boards, and internal review boards. SMA personnel also formulate and communicate the SMA TA position on significant technical issues, disposition changes, waivers, deviations, and exceptions to respective program/project SMA requirements. SMA TA independently assess program/project-owned risks and execute, implement, and otherwise maintain the checks and balance of safety and quality standards. It is critical that this money is independent of mission funding to ensure there is an independent process for identifying and managing safety and quality concerns.

SCIENCE AND ENGINEERING

Centers maintain highly technical laboratories, critical capabilities, and associated specialized skills and equipment thereby ensuring mission readiness. These capabilities support Center mission work ensuring required technical capabilities are mission ready. Such functions include providing for the on-site capability to fabricate test articles, test fixtures, prototype, proto-flight, and flight articles necessary to support the design, development, and testing of research models, instruments, flight and related ground support hardware, technical components, and laboratory test apparatus. Centers also provide for the on-site capability to support research, development testing, and sustaining engineering for science and technologies necessary to support their program activities. These funds are specific to the centers because of the variety and distribution of highly technical work that is spread across the Agency's nine distinct centers, Headquarters, and other installations.

CENTER INVESTMENTS

Ensuring the right talent and technical capabilities are mission-ready for NASA priority projects and missions, centers utilize investment funding to maintain their technical skills and capabilities in support of local mission work. Investments fund institutional research that aligns with assigned center roles, development projects, and business innovation. Centers use a competitive approach to achieve this mission work and supports NASA's commitment to innovative and creativity. Center investments are also utilized through bid and proposal process ensuring mission work is distributed to the appropriate center and technical area. Centers have the flexibility to support independent research and development (IRAD) pursuing collaboration with academia and private industry so that NASA has the leading-edge capabilities needed to support NASA's missions, today and in the future.

CENTER ENGINEERING, SAFETY, & OPERATIONS

ENGINEERING TECHNICAL AUTHORITY

The Office of the Chief Engineer (OCE) develops and distributes standards, policies, and guidance related to engineering safety, quality, and process. At each Center, personnel are dedicated to providing independent oversight of programs and projects in support of safety and mission success as prescribed in the NASA technical authority model, thus ensuring requisite policies and processes are successfully implemented, thereby upholding NASA's high standard of engineering excellence. Key technical authority positions, including managers in research and engineering, testing, and fabrication, use these funds to conduct reviews, oversight, and management of quality and safety standards independent of mission directorates. These activities are a crucial part of NASA's checks and balances, which ensure the highest standard of engineering excellence and reporting.

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Construction of Facilities	387.7	315.6	**348.1**	353.4	360.5	367.6	376.6
Environmental Compliance and Restoration	58.1	74.7	**76.2**	79.4	81.0	82.7	82.7
Total Budget	**445.8**	**390.3**	**424.3**	**432.8**	**441.5**	**450.3**	**459.3**

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

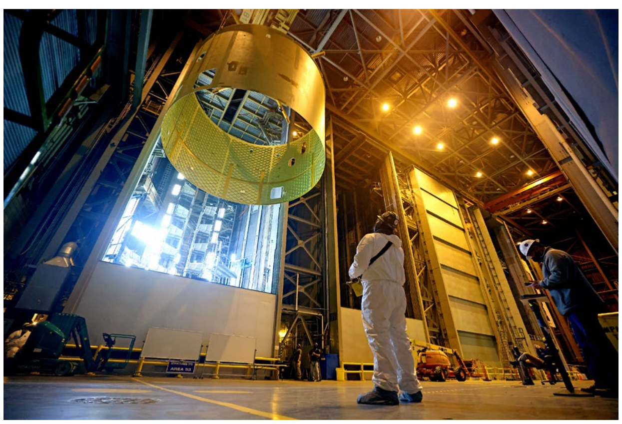
CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Construction of Facilities	387.7	315.6	**348.1**	353.4	360.5	367.6	376.6
Environmental Compliance and Restoration	58.1	74.7	**76.2**	79.4	81.0	82.7	82.7
Total Budget	**445.8**	**390.3**	**424.3**	**432.8**	**441.5**	**450.3**	**459.3**
Change from FY 2022 Budget Request			**34.0**				
Percent change from FY 2022 Budget Request			**8.7%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



Inside the Michoud Assembly Facility (MAF), engineers prepare NASA's Space Launch System (SLS) for Artemis missions. This massive facility provides unique manufacturing space and is critical to NASA's exploration missions.

Through the Construction and Environmental Compliance and Restoration (CECR) account, NASA manages two themes related to the Agency's large footprint and activities: capital repairs and improvements to NASA's infrastructure, and environmental compliance and restoration activities. Activities related to the design, construction, and demolition of infrastructure, including utility systems and facilities, are funded through Construction of Facilities (CoF). Environmental compliance, cleanup, and restoration activities are funded through Environmental Compliance and Restoration (ECR).

More than 83 percent of NASA's infrastructure is beyond its design life, posing significant risk of failure, inefficiency, and impacts to health and wellness. Apollo-era infrastructure is inefficient and costly to maintain, as well as insufficient to accomplish NASA's future missions. Commercialized space, continuous human presence on the Moon, Earth and space science, advanced science and engineering research, and long-term Mars expeditions require facilities with leading-edge capabilities. As NASA's Office of Inspector General (OIG) noted in its annual NASA's Top Management and Performance Challenges (2021), "while NASA strives to keep these facilities operational, the Agency faced a deferred maintenance backlog of $2.8 billion as of 2021." This has resulted in unscheduled maintenance, costing up to three times more than scheduled maintenance to repair or replace equipment after it has failed. To address these challenges, CECR is focused on modernizing and consolidating NASA's infrastructure into fewer, more efficient, and more sustainable facilities while repairing and upgrading failing infrastructure.

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

CECR funding ensures that NASA’s assets are ready, available, and appropriately sized to conduct NASA’s current and future missions, while remaining compliant with the Agency and governmental environmental regulations. NASA's 2022 Strategic Plan (Objective 4.2) challenges NASA to "Transform mission support capabilities for the next era of aerospace" on which mission work depends. CECR programs endeavor to create a more sustainable and capable NASA, while striving to reduce the Agency’s physical footprint and environmental burden.

CECR Priorities

CECR focuses on ensuring the viability and excellence of mission-critical infrastructure while also supporting NASA's commitment to environmental stewardship and sustainability. The activities below outline how CECR allocations are made:

- Construct new facilities and replace or upgrade existing infrastructure to support NASA's mission requirements and timeline;
- Design facilities and infrastructure solutions to support construction and repairs while optimizing sustainability, increasing efficiency, and reducing NASA's footprint;
- Demolish unneeded and degraded facilities to avoid costs and improve sustainability;
- Invest in energy and water savings opportunities to improve NASA's environmental stewardship; and
- Comply with mandates, regulations, and general best practices to protect the health and wellness of the environment, NASA's workforce, and the general public.

Balancing SSMS & CECR

NASA's mission support portfolio is divided between two accounts: Safety, Security, and Mission Services (SSMS); and Construction and Environmental Compliance and Restoration (CECR). The Mission Support Directorate (MSD) utilizes both accounts to maintain NASA's critical infrastructure. MSD must balance spending on the maintenance of assets and infrastructure, repairs and renewal of failing assets, and the replacement and demolition of obsolete assets. Required maintenance activities drive SSMS spending decisions, while repairs, renewals (including new construction), and associated demolition drive CECR spending.

Much of NASA's infrastructure dates back to Apollo-era space exploration. Maintenance activities funded by SSMS are necessary to prevent costly delays to missions and risks to health and safety. Meanwhile, failures require immediate repairs and account for an increasing share of the maintenance budget. These activities are vital to support evolving mission requirements. MSD takes an Agency-wide approach to make difficult trade-off decisions that ensure critical capabilities and assets are mission-ready, while also investing in the long-term asset health, sustainability, and footprint reductions that ensure NASA's future mission success.

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

EXPLANATION OF MAJOR CHANGES IN FY 2023

Funding levels reflect the requirements for the institutional and programmatic projects selected for FY 2023, as well as anticipated requirements to meet environmental compliance and corrective action commitments. Some of the most significant projects in FY 2023 include:

- Replace the Wallops Island Causeway Bridge at Wallops Island, a component facility of GSFC;
- Construct the Aircraft Logistics and Operations Facility at JSC;
- Replace the electrical distribution equipment in the South Wing of the Operations and Checkout Building at KSC;
- Modify the launch infrastructure at KSD;
- Rehabilitate the HVAC system in KSC's Launch Control Center (LCC); and
- Complete the beam waveguide antennae at the Goldstone and Canberra Deep Space Communication.

Environmental Resilience and Sustainability

In addition to mission requirements and center conditions, NASA's funding decisions were also driven by a need to increase environmental resilience to ensure critical infrastructure is sustained for future missions. The emphasis on sustainability lowers operations and maintenance costs, which can then be reallocated to mission-critical capabilities and facilities. These investments ensure NASA's continued stewardship of the environment while protecting vital assets.

Funding levels reflect the requirements for the institutional and programmatic projects selected for FY 2023, as well as anticipated requirements to meet environmental compliance and corrective action commitments.

ACHIEVEMENTS IN FY 2021

CECR reached significant milestones despite continued challenges and limited access due to COVID-19 restrictions. The following list provides highlights from high-priority FY 2021 projects. A more robust list with project descriptions is available in each program section.

- Constructed, repaired, or revitalized institutional infrastructure and facilities that have capabilities and impacts that span across centers and enable all mission work:
  - Began new construction of the Vehicle and Aerospace Ground Equipment Maintenance Facility at Armstrong Flight Research Center (AFRC), which will consolidate the functions of five degraded buildings;
  - Replaced a section of the roof of the Michoud Assembly Facility (MAF) building 103;
  - Repaired the degraded and dangerous electrical distribution systems at Glenn Research Center (GRC);
  - Replaced the natural gas system at White Sands Test Facility (WSTF); and
  - Installed seismic bracing to protect assets against earthquakes at Jet Propulsion Laboratory (JPL).

- Supported exploration mission work with the construction, repair, or revitalization of critical facilities and infrastructure:
  - Modified Kennedy Space Center's (KSC's) launch infrastructure to support Space Launch System (SLS) and other exploration mission requirements;

- Upgraded the communication infrastructure of Booster Fabrication Facility Complex at KSC;
- Continued modifications to the Michoud Assembly Facility (MAF) to enable SLS work; and
- Replaced the roofs of the manufacturing building and engineering and administration building at KSC.

- Supported operations in space mission work with the construction, repair, or revitalization of critical facilities and infrastructure:
  - Completed testing activities for the Deep Space Network Aperture Enhancement (DEAP) project in Madrid and deliver it into operation;
  - Began antenna fabrication work for the new DSS-23 antenna; and
  - Replaced the beam waveguide antenna drives at Goldstone Deep Space Communication Complex for greater reliability.
- Demolished unneeded or degraded facilities to support a more sustainable NASA with a smaller footprint while avoiding repair and operational costs:
  - Demolished the Indian River Bridge at KSC.
- Invested in energy savings projects that reduce operational costs and utility usage across NASA:
  - All new construction is done with efficient materials for better energy and water usage;
  - Installed energy efficiency improvements and implemented energy improvement measures and strategies at Ames Research Center (ARC) and Stennis Space Center (SSC); and
  - Optimized the AFRC HVAC System, specifically in building 4838.
- Conducted facility planning and design associated with all construction and revitalization projects to ensure optimal consolidation, energy savings, cost-effectiveness, and other outcomes:
  - Conducted Institutional CoF facility planning and design as a routine requirement for all projects; and
  - Planned Mission CoF projects within mission activities (not funded by CoF).
- Maintained NASA's commitment to environmental stewardship by conducting critical cleanup efforts, maintaining compliance with regulatory requirements, and managing environmental issues:
  - Began abatement and demolition of Bravo Test Stands and Control House at Santa Susana Field Laboratory;
  - Conducted groundwater and soil remediation activities across NASA;
  - Completed the Preliminary Assessment field work and initiated the site inspections of per- and polyfluoroalkyl substance (PFAS) contamination Agency-wide;
  - Continued remedial system operation, maintenance, and groundwater monitoring and analysis across NASA and providing progress reports to applicable state and Federal stakeholders; and
  - Continued engagements with affected communities, like Tribal nations.

WORK IN PROGRESS IN FY 2022

CECR will continue to enable critical mission work in FY 2022 while maintaining NASA's dedication to environmental stewardship. The following list highlights high-priority FY 2022 projects, subject to final FY 2022 funding levels. A more robust list with project descriptions is available in each program section.

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

- Construct, repair, or revitalize institutional infrastructure and facilities that have capabilities and impacts that span across centers and enable all mission work:
  - Construct the Johnson Space Center (JSC) Operations and Maintenance Facility to consolidate and enhance foundational support services for all vital mission work at the Center, including the International Space Station, Orion, Commercial Crew, and numerous scientific and engineering research programs;
  - Repair facilities damaged by Hurricane Zeta at Marshall Space Flight Center (MSFC) and SSC to restore operational capabilities and efficiencies, as well as ensure safety and compliance;
  - Restore the reliability of the Arc Jet Gas Flow Controllers at ARC;
  - Repair AFRC's electrical substation to improve reliability and efficiency;
  - Upgrade the safety and reliability of KSC's institutional power systems; and
  - Restore the main base electrical infrastructure at Wallops Flight Facility (WFF).
- Support exploration mission work with the construction, repair, or revitalization of critical facilities and infrastructure:
  - Modify the launch infrastructure at KSC for SLS activities and new exploration missions;
  - Rehabilitate KSC's Launch Control Center HVAC system to enable critical mission work;
  - Replace Michoud Assembly Facility's (MAF's) roof and relocate the fan house to enable SLS construction and manned spaceflight;
  - Repair and upgrade Vehicle Assembly Building's (VAB's) Water Distribution System at KSC; and
  - Repair MAF roadways.
- Support operations in space mission work with the construction, repair, or revitalization of critical facilities and infrastructure:
  - Complete the DEAP BWG antennae at the Goldstone and Canberra Deep Space Communication Complexes;
  - Upgrade the switchgear to provide redundancy and ensure reliability at a location designated the “Apollo” site; and
  - Install an additional underground backup power feed from one location, designated the “Mars” site, to the “Apollo” site.
- Demolish unneeded or degraded facilities to support a more sustainable NASA with a smaller footprint while avoiding repair and operational costs:
  - Demolition of approximately 11 facilities with more than 253,000 square feet, including the Research Laboratory and the Pearl Young Conference Center at Langley Research Center (LaRC).
- Invest in energy savings projects that reduce operational costs and utility usage across NASA:
  - Construct a second thermal energy storage tank at MSFC; and
  - Upgrade the energy monitoring and control system at GRC.
- Conduct facility planning and design associated with all construction and revitalization projects to ensure optimal consolidation, energy savings, cost-effectiveness, and other outcomes:
  - Conduct Institutional CoF facility planning and design as a routine requirement for all projects; and
  - Plan Mission CoF projects within mission activities (not funded by CoF).

- Maintain NASA's commitment to environmental stewardship by conducting critical cleanup efforts, maintaining compliance with regulatory requirements, and managing environmental issues:
  - Continue to demolish Bravo Test Stands and begin demolition of Coca Test Stands at Santa Susana Field Laboratory (SSFL);
  - Complete site investigations of per- and polyfluoroalkyl substance (PFAS) contamination Agency-wide;
  - Continue operation of groundwater treatment systems and continue long term monitoring and management of air, groundwater, surface water, and treatment efforts;
  - Continue restoration of impacted soil across NASA; and
  - Implement ECR policies and provide critical support to stakeholders, including planning, engagements, communications, guidance and other responses to inquiries, and program management.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

CECR will continue to enable critical mission work in FY 2023 while maintaining NASA's dedication to environmental stewardship. The following list highlights high-priority FY 2023 projects. A more robust list with project descriptions is available in each program section.

- Construct, repair, or revitalize institutional infrastructure and facilities that have capabilities and impacts that span across centers and enable all mission work:
  - Replace the vital Wallops Island Causeway Bridge, the single point of access to Wallops Island;
  - Construct the Aircraft Logistics and Operations Facility at JSC;
  - Replace the Ames Power Management System at ARC; and
  - Repair the Greenbelt Parkway Bridge at Goddard Space Flight Center (GSFC).
- Support exploration mission work with the construction, repair, or revitalization of critical facilities and infrastructure:
  - Continue modifying the launch infrastructure at KSC for SLS activities and new exploration missions;
  - Renovate the interior infrastructure of KSC’s Booster Fabrication Facility; and
  - Refurbish the cranes needed to support the SLS and Artemis Campaign Booster flight hardware operations in the MAF.
- Support operations in space operations work with the construction, repair, or revitalization of critical facilities and infrastructure:
  - Complete the DEAP BWG antennae at the Goldstone and Canberra Deep Space Communication Complexes;
  - Build redundant data and signal processing centers to ensure the security and storage of vital mission data gathered during explorational and scientific missions; and
  - Replace fire detections systems at Goldstone for improved site operations.
- Demolish unneeded or degraded facilities to support a more sustainable NASA with a smaller footprint while avoiding repair and operational costs:
  - Demolition of approximately 340,000 square feet, including the Vibrations and Acoustic Test Facility at JSC.

- Invest in energy savings projects that reduce operational costs and utility usage across NASA:
  - Implement energy conservation measures and upgrade control systems for improve efficiency at JSC;
  - Repair vacuum jacketed electrical lines at LaRC for improved system efficiency; and
  - Install critical water meter across the Agency to improve NASA's overall consumption and reduce environmental burden.
- Conduct facility planning and design associated with all construction and revitalization projects to ensure optimal consolidation, energy savings, cost-effectiveness, and other outcomes:
  - Master planning for all projects, including efforts to consolidate work and leverage work-from-home options which have proven effective during the Agency's response to COVID-19;
  - Study and assessment of engineering, design and construction management, facility operations and maintenance, condition-based maintenance, and facility utilization;
  - Support for engineering in facilities management systems, oversight, and capital leveraging research;
  - Assessment of footprint reduction, consolidation, and environmental stewardship options; and
  - Plan Mission CoF projects within mission activities (not funded by CoF).
- Maintain NASA's commitment to environmental stewardship by conducting critical cleanup efforts, maintaining compliance with regulatory requirements, and managing environmental issues:
  - Continue the demolition of Coca Test Stands at SSFL;
  - Continue operation of groundwater treatment systems and continue long term monitoring and management of air, groundwater, surface water, and treatment efforts Agency-wide;
  - Continue restoration of impacted soil across NASA; and
  - Implement ECR policies and provide critical support to stakeholders, including planning, engagements, communications, guidance and other responses to inquiries, and program management.

Themes

CONSTRUCTION OF FACILITIES (COF)

CoF funds capital repairs and improvements to NASA's infrastructure to provide NASA programs and projects with the research, development, and testing facilities required to accomplish their missions. CoF repairs the facilities that have suffered degradations, recent failures, or deterioration from inadequate maintenance over time. Due to mission priorities, projects to address immediate needs may displace renewal or new construction projects planned for the replacement of obsolete facilities. Such tradeoffs preclude the new construction of facilities and infrastructure that would reduce costs and increase sustainability in the long run.

CoF is comprised of two programs: Institutional CoF and Programmatic CoF. Institutional CoF activities are divided across five project definitions: discrete projects costing over $10 million; minor revitalization and construction less than $10 million; facility planning and design; demolition; and investments in energy savings. Programmatic CoF is focused on mission directorate-funded projects for specialized capabilities that align to specific NASA mission, separated between two project definitions of either discrete projects costing over $10 million or minor revitalization and construction costing less than $10 million.

NASA's CoF budget funds the Agency's highest priority construction projects and continues to replace obsolete and deteriorating facilities that directly support NASA's mission. Institutional CoF is balanced does not fund routine maintenance and repairs with estimates of less than $1 million.

ENVIRONMENTAL COMPLIANCE AND RESTORATION (ECR)

ECR mitigates environmental risk at NASA installations and NASA-owned industrial plants supporting NASA activities. The remediation program at Santa Susana Field Laboratory site in California consumes approximately 42 percent of the ECR annual budget. ECR also supports remediation at current or former sites where NASA operations have contributed to environmental problems or where the Agency is legally obligated due to past releases of pollutants, including emerging contaminants such as polyfluoroalkyl substances (PFAS).

At every center, ECR is investigating contaminated sites; remediating contaminated soil, water, and other media; and monitoring for continued compliance with Agency objectives and obligations. ECR ensures NASA’s compliance with environmental requirements, including the Resource Conservation and Recovery Act (RCRA); Comprehensive Environmental Response, Compensation, Liability Act (CERCLA); state regulatory requirements; consent orders; and legal obligations.

CONSTRUCTION OF FACILITIES

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Institutional CoF	262.9	205.8	**240.6**	353.4	360.5	367.6	376.6
Exploration CoF	66.2	89.3	**86.2**	0.0	0.0	0.0	0.0
Space Operations CoF	25.2	20.5	**21.3**	0.0	0.0	0.0	0.0
Science CoF	33.4	0.0	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**387.7**	**315.6**	**348.1**	**353.4**	**360.5**	**367.6**	**376.6**
Change from FY 2022 Budget Request			**32.5**				
Percent change from FY 2022 Budget Request			**10.3%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The newly constructed liquid hydrogen (LH2) storage tank at Launch Pad 39B of KSC's multiuse spaceport, shown here, is vital infrastructure that supports Aretmis launches and long-term lunar missions.

NASA's Construction of Facilities (CoF) program includes both institutional and programmatic construction projects. These projects reduce facility-related risk to mission success, increase sustainability, and improve technical infrastructure capabilities in support of NASA missions. CoF provides for the design and construction of facilities projects that enable NASA's infrastructure to meet mission needs. The CoF program mitigates risks associated with real property assets, defined by NASA as "risks to infrastructure, information technology, resources, personnel, assets, processes, operations, occupational safety and health, environmental management, security, or programmatic constraints that affect capabilities and resources necessary for mission success, including institutional flexibility to respond to changing mission needs and compliance with internal (e.g., NASA) and external requirements (e.g., Environmental Protection Agency or Occupational Safety and Health Administration regulations)." Outyear funding for Programmatic CoF shows zero in the budget table, but NASA anticipates that in each budget year, programmatic CoF funds will be identified.

CoF Priorities

CoF spans two programs: institutional and programmatic (for a full description of these two program areas, see the Program Elements section). All CoF projects are prioritized through Agency and center

CONSTRUCTION OF FACILITIES

leadership based upon immediate mission requirements and long-term NASA sustainability. Project priorities are best defined by a project's ability to address the following desired outcomes (for a full description of these project categories, see the Program Elements in each program section):

- Construct or revitalize facilities and infrastructure with discrete projects (greater than $10 million) and minor projects (less than $10 million) to meeting mission and center requirements for NASA priorities;
- Plan and design facilities to ensure optimal outcomes and comply with statutory and mission requirements;
- Demolish unnecessary or degraded buildings following the consolidation or new construction of replacement facilities to reduce costs and NASA's footprint; and
- Invest in energy savings projects that significantly change utility usage, including energy and water, for reduced operational costs and increased sustainability.

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

ACHIEVEMENTS IN FY 2021

See each program area for a complete list of achievements in FY 2021.

WORK IN PROGRESS IN FY 2022

See each program area for a complete list of work in progress in FY 2022.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

See each program area for a complete list of key achievements planned for FY 2023.

Program Elements

INSTITUTIONAL CONSTRUCTION OF FACILITIES (INSTITUTION COF)

Institutional CoF addresses infrastructure and facilities that span mission areas and enable the work of a center. Horizontal infrastructure and center-wide systems, such as roads and utilities, support all mission activities and are therefore considered "institutional." Institutional CoF also funds activities that support the overall Agency goals of reducing operating costs, maintenance obligations, and utility usage through demolition and energy savings projects.

PROGRAMMATIC CONSTRUCTION OF FACILITIES (PROGRAMMATIC COF)

Programmatic CoF is funded by Mission Directorates for construction of specialized capabilities that directly support specific NASA missions, with appropriate funding transferred into CoF during the formulation of each budget year. Facilities and infrastructure supporting execution of specific mission directorate requirements or having a unique capability required specifically for the execution of mission directorate programs and/or projects are funded through Programmatic CoF. Construction, repairs, and revitalization funded by Programmatic CoF do not have center-wide or Agency-wide applications. Because projects funded through Programmatic CoF are unique to the missions they support, the description of projects are included below by mission area.

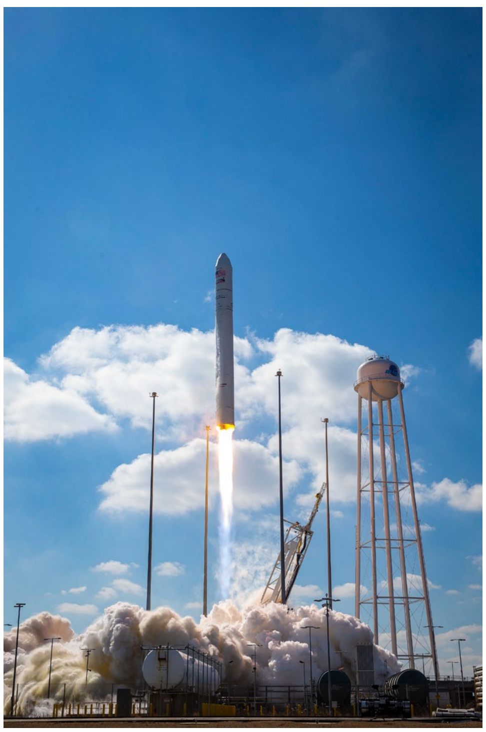
INSTITUTIONAL COF

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**262.9**	**205.8**	**240.6**	**353.4**	**360.5**	**367.6**	**376.6**
Change from FY 2022 Budget Request			**34.8**				
Percent change from FY 2022 Budget Request			**16.9%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.



Shown here is a resupply mission to the International Space Station (ISS) launching from Wallops Flight Facility (WFF), a mid-atlantic site that is accessed by a single bridge in need of repair.

Institutional CoF sustains a state of readiness in NASA's physical infrastructure. Real property assets include all horizontal and vertical infrastructure and the associated collateral equipment. Repair and revitalization projects are prioritized using a risk-informed process that evaluates mission risks in terms of safety, schedule, cost, and technical capability. For each major facility replacement project, NASA develops a business case that includes a cost-benefit analysis.

NASA maintains an ongoing effort to identify, quantify, and prioritize institutional risks. Significant risks to a mission attributed to institutional real property are mitigated through the Institutional CoF program. The criticality of mission risks may be reassessed as the risk posture changes due to mission and/or infrastructure condition. Currently, NASA has identified $5.4 billion worth of repairs and projects to mitigate known risks and optimize mission critical capabilities.

Institutional CoF Priorities

Institutional CoF funding evolves based on mission requirements to address critical risks that threaten NASA's prioritized missions. Institutional CoF is divided across different projects depending on facility and infrastructure criticality, long-term sustainability, and mission needs, with an emphasis on risk reduction:

Reduce institutional risks, including risks to personal safety and deficiencies, and enable missions with discrete (greater than $10 million) and minor (less than $10 million) projects that address critical mission requirements

- Demolish unnecessary and degraded buildings to avoid costs, eliminate risks, and reduce NASA's overall footprint for increased sustainability;

INSTITUTIONAL COF

- Plan and design facilities to optimize capabilities, enhance sustainability, and comply with all Federal and state obligations; and
- Invest in energy savings projects that enhance sustainability and support NASA's commitment to environmental stewardship.

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

ACHIEVEMENTS IN FY 2021

NASA continued projects initiated in FY 2021 and prior years along with five new discrete projects and 13 minor projects.

Discrete Projects

- Initiated construction of the Vehicle and Aerospace Ground Equipment Maintenance Facility at AFRC, which will consolidate the functions of five degraded buildings into an approximately 25,000 square foot, state-of-the-art facility to support NASA's aeronautics research and aviation advancement;
- Modified or upgrade the launch infrastructure at KSC for the Space Launch System (SLS) (e.g., nitrogen system, environmental controls, air supply);
- Replaced a section of the roof of the Michoud Assembly Facility (MAF) building 103 (Phase 2 of 5), an approximately 1.7 million square foot facility that houses NASA's major system construction and threatens mission milestones and employee safety with its quickly degrading infrastructure;
- Revitalized MSFC’s failing HVAC, water, and energy systems within the Structures, Dynamics, and Thermal Vacuum Laboratory (building 4619), one of NASA's mission-critical laboratories with unique capabilities in structural strength and dynamics testing, experimental fluids and environmental testing, guidance, navigation, and control simulation; and
- Repaired SSC's potable water system (Phase 3 of 4), a more than 50-year-old system of around 65 miles of iron pipe that is prone to failures, causing damage and mission-threatening delays.

Minor Projects

- Repaired water and steam distribution systems (including cooling towers) at GRC (Phase 4 of 5);
- Repaired the degraded and dangerous electrical distribution systems at GRC (Phase 3 of 5);
- Restored the main base electrical infrastructure for increased safety and reliability at WFF (Phase 1 of 2);
- Restored vital, cross-Center systems at GSFC, including fire alarms and chillers;
- Installed seismic bracing to protect assets against earthquakes at JPL;
- Replaced central heating and cooling systems at JSC;
- Replaced the natural gas system at WSTF (Phase 1 of 2);
- Upgraded the KSC power systems with safety and reliability features (Phase 4 of 5);
- Rehabbed vital utility and electrical systems at LaRC including tunnels, environmental controls, and electrical distribution systems (Phase 1 of 2);
- Installed a utility control system at MSFC for increase efficiency and reliability;
- Repaired electrical systems at MSFC, including increased safety measures;

INSTITUTIONAL COF

- Repaired and upgrade vital electrical systems at SSC that threatened employee safety and mission success, including new arc flash mitigation measures as well as electrical distribution and generation systems; and
- Repaired SSC's canal impoundment system, miter gates, and closure valves to allow mission-critical transportation through the waterways.

Demolition

- Initiated demolition of the Indian River Bridge at KSC; and
- Initiated demolition of Building 4200 at MSFC.

Energy Savings

- Installed various energy efficiency improvements at ARC;
- Implemented energy improvement measures and strategies at SSC; and
- Optimized the AFRC HVAC System, specifically in building 4838.

Facility Planning and Design

Institutional CoF conducted facility planning and design as a routine requirement for all projects.

WORK IN PROGRESS IN FY 2022

NASA will continue projects initiated in FY 2022 and prior years along with 3 new discrete projects and 13 minor projects.

Discrete Projects

- Construct the JSC Operations and Maintenance Facility to consolidate and enhance foundational support services for all vital mission work at the Center, including the International Space Station, Orion, Commercial Crew, and numerous scientific and engineering research programs;
- Upgrade LaRC's core and cross-Center electrical infrastructure, including the underground 22 kilovolt (kV) electrical distribution infrastructure, to support vital mission activities and research conducted in LaRC's wind tunnels, research labs, flight system integration and testing facilities, and all other offices and buildings; and
- Repair facilities damaged by Hurricane Zeta at MSFC and SSC to restore operational capabilities and efficiencies, as well as ensure safety and compliance.

Minor Projects

- Restore the reliability of the Arc Jet Gas Flow Controllers at ARC;
- Repair Center-wide fire systems at AFRC (Phase 1 of 2);
- Repair AFRC's electrical substation to improve reliability and efficiency (Phase 1 of 2);
- Repair GRC's storm sewer system (Phase 3 of 3);
- Repair the electrical distribution system at GRC to increase safety and reliability (Phase 4 of 5);
- Upgrade the electrical feeders at GSFC to increase safety and reliability (Phase 2 of 2);
- Install Center-wide fire alarm upgrades at GSFC for improved safety (Phase 2 of 2);
- Restore the main base electrical infrastructure at WFF (Phase 2 of 2);
- Build seismic bracing at JPL to protect equipment, assets, and research against earthquakes;

INSTITUTIONAL COF

- Replace JPL's electrical substation to address vital electrical needs and improve reliability;
- Replace potable water storage and elevated tanks at JSC for Center-wide operations;
- Upgrade the safety and reliability of KSC's institutional power systems (Phase 5 of 5); and
- Repair SSC's sewage system and water treatment facilities for improve efficiency (Phase 1 of 2).

Demolition

- Demolition of approximately 11 facilities with more than 253,000 square feet, including the Research Laboratory and the Pearl Young Conference Center at LaRC.

Energy Savings

- Construct a second thermal energy storage tank at MSFC; and
- Upgrade the energy monitoring and control system at GRC.

Facility Planning and Design

Institutional CoF conducts facility planning and design as a routine requirement for all projects.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

NASA's Institutional CoF program for FY 2023 includes three discrete projects, 11 minor projects, three energy savings investment projects, and numerous demolition projects. Depending on appropriated budgets and because all CoF projects are prioritized based on criticality and mission urgency, NASA may address some deferred projects before addressing the planned FY 2023 activities.

Discrete Projects

- Replace the vital Wallops Island Causeway Bridge that is the single point of access to Wallops Island, a component facility of GSFC:
  - FY 2023 Estimated $55 million; Total Project Costs $55 million;
  - Replace the existing bridge that is showing signs of deterioration and threatens collapse;
  - Maintain open access to the island during construction to avoid delays to mission work, including International Space Station (ISS) resupply missions; and
  - Avoid catastrophic and potentially life-threatening loss of this major infrastructure.
- Construct the Aircraft Logistics and Operations Facility at JSC to consolidate and modernize existing, critical facilities:
  - FY 2023 Estimated $20 million; Total Project Costs $20 million;
  - Resolve concerns with safety, security, efficiency, cost effectiveness, sustainability, and usability that persist with existing degraded facilities; and
  - Consolidate to reduce Agency footprint and construct a modern facility with better energy and water usage infrastructure for better environmental stewardship.
- Replace the electrical distribution equipment in South Wing of the Operations and Checkout (O&C) Building at KSC:
  - FY 2023 Estimated $23.2 million; Total Project Costs $23.2 million;
  - Replace the over 56-year-old electrical power distribution and control equipment that has been unreliable and threatens failure; and

INSTITUTIONAL COF

- Ensure the continued, efficient, and sustainable operation of the South Wing of the O&C Building, which houses payload processing areas, control rooms, and logistics areas.

Minor Projects

Institutional CoF will spend an estimated $63.0 million on minor projects in FY 2023, prioritized based on asset criticality and mission urgency. NASA may reprioritize some projects, depending on final allocations from Congress and evolving mission requirements and asset conditions.

- Repair Center-wide building envelopes at AFRC that will be resilient to extreme desert weather conditions and sonic booms and increase the lifespan of existing facilities;
- Replace the Ames Power Management System (APMS), the failing, Center-wide electrical power management system at ARC which supports all operations and mission work;
- Repair high voltage electrical transformers at GRC's Substation J that support Center-wide operations and have exceed their design lives and are actively failing;
- Renew by incremental repair the over 70-year-old, antiquated, high-voltage, electrical cables that sustain Center-wide operations at GRC by installing modern, plastic-insulated cabling (Phase 2 of 4);
- Repair the Greenbelt Parkway Bridge at GSFC, which is the Center's primary access point and critical infrastructure for all mission activities at the Center;
- Replace and upgrade the switchgear in buildings 170 and 158 at JPL;
- Replace and upgrade the switchgear in building 230 at JPL, which will increase the current capacity, enhance monitoring capabilities, and improve safety and reliability for electrical power distribution;
- Repair the utility tunnels at LaRC to increase the reliability of mission-critical facilities, including steam, high pressure air, service air, water, and communications (Phase 2 of 2);
- Repair the central steam plant at LaRC that sustains Center-wide critical utility systems (Phase 1 of 2);
- Replace degraded water piping systems in building 4708 at MSFC to prevent further water damage to critical areas including flight hardware, high bays, test labs, clean rooms, technical shops, and offices; and
- Mitigate the threat of low voltage arc flash issues by making sitewide electrical repairs at SSC, reducing safety hazards to personnel, fire hazards, and deteriorating infrastructure.

Energy Savings Investments

Institutional CoF will spend an estimated $8.0 million on energy savings investments in FY 2023, resulting in an estimated $0.7 million annually in avoided utilities expenditures while driving to more sustainable Agency infrastructure. These projects support NASA's dedication to environmental stewardship and efficiency.

- Implement energy conservation measures and upgrade control systems for improve efficiency at JSC;
- Repair vacuum jacketed electrical lines at LaRC for improved system efficiency; and
- Install critical water meter across the Agency to improve NASA's overall consumption and reduce environmental burden.

INSTITUTIONAL COF

Demolition of Facilities

Institutional CoF will spend an estimated $45 million on demolition to reduce the Agency’s footprint, reduce operational costs, and increase environmental sustainability.

- Demolition of multiple facilities with more than 340,000 square feet, including the Vibrations and Acoustics Test Facility at JSC.

Facility Planning and Design

Institutional CoF will spend an estimated $26.4 million on facility planning and design in FY 2023. Facility planning and design is a requirement for all CoF projects to ensure optimal outcomes, including consolidation and utility usage.

- Master planning for all projects, including efforts to consolidate work and leverage work-from-home options which have proven effective during the Agency's response to COVID-19;
- Study and assessment of engineering, design and construction management, facility operations and maintenance, condition-based maintenance, and facility utilization;
- Support for engineering in facilities management systems, oversight, and capital leveraging research; and
- Assessment of footprint reduction, consolidation, and environmental stewardship options.

EXPLORATION COF

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**66.2**	**89.3**	**86.2**	**0.0**	**0.0**	**0.0**	**0.0**
Change from FY 2022 Budget Request			**-3.1**				
Percent change from FY 2022 Budget Request			**-3.5%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Exploration Construction of Facilities (CoF) supports NASA's exploration missions, including the Space Launch System (SLS), Orion, and Exploration Ground Systems (EGS) programs. Exploration CoF is managed in collaboration with institutional projects but funded through the Deep Space Exploration Systems Mission Directorate and Space Operations Mission Directorate (SOMD).

Shown here are engineers integrating NASA's Space Launch System (SLS) rocket with the launch vehicle stage adapter (LVSA) at Kennedy Space Center's Vehicle Assemble Building (VAB) using advanced cranes and unique mechanical systems.

Exploration CoF Priorities

Exploration construction priorities in FY 2022 continue to support facility upgrades and modernization for the Artemis campaign at the Kennedy Space Center (KSC) and the Michoud Assembly Facility (MAF).

EXPLANATION OF MAJOR CHANGES IN FY 2022

None.

ACHIEVEMENTS IN FY 2021

EGS continues development of programmatic infrastructure modifications necessary to support SLS and Orion launch processing operations.

Discrete Projects

- Modified KSC's launch infrastructure to support SLS and other exploration mission requirements:
  - Installed the Emergency Egress System (EES) to enable emergency evacuation of the flight crew from the Mobile Launcher (ML);
  - Constructed the Environmental Control System (ECS) to continuously maintain critical temperature and humidity air supply for SLS and Orion flight systems during launches;
  - Upgraded nitrogen compression pumps, vaporizers, valves, and piping configurations; and

EXPLORATION COF

- Addressed infrastructure concerns resulting from long-term deferred maintenance, including code compliance updates to replace obsolete systems and increase efficiency.

Minor Projects

- Replaced KSC's Logistic Facility HVAC system to meet design life cycle replacement requirements;
- Replaced the roofs of the manufacturing building and engineering and administration building at KSC;
- Upgraded the communication infrastructure of BFF Complex at KSC, including the replacement of legacy wiring and critical information technology equipment;
- Continued refurbishing the Neil Armstrong Operations and Checkout Building to address defects in the exterior surface of the wall and enable clean room activities for Orion capsule processing at KSC; and
- Continued modifications to the MAF to enable SLS work, including replacement of the steam and water system, pumping stations, electrical systems and transformers, and major equipment installations (e.g., cranes, weld tools, gas, pressure systems).

Facility Planning and Design

- Began to design VAB rehabilitation to include heavy-weight cranes in critical facilities;
- Began the designs to replace the aging HVAC systems and associated controls throughout Launch Control Center (LCC) and VAB, which will address long-term deferred maintenance, significantly increase energy efficiency, and remove hazardous materials;
- Designed all scheduled projects included in MAF roof replacement and associated redesign (Phases 2 through 4); and
- Designed BFF Complex improvements, including the Oxygen Deficiency Monitoring System (OMDS), replacement of remaining roofs, interior renovations, and crane refurbishment.

WORK IN PROGRESS IN FY 2022

Exploration CoF will continue infrastructure modifications necessary to support SLS and Orion launch operations, along with other exploration missions.

Discrete Projects

- Modify the launch infrastructure at KSC:
  - FY 2022 Estimate: $3.5M to complete project funding; Total Project Estimate: $61.6M;
  - Funded jointly with Institutional CoF to ensure success in future mission launches;
  - Upgrade critical systems for nitrogen, temperature and humidity control, air supply, fabrication, and emergency evacuation; and
  - Enable the Artemis campaign and long-distance exploration programs with SLS activities.

- Rehabilitate KSC's LCC HVAC system:
  - FY 2022 Estimate: $15.8 million to fund Phase 1 of 2; Total Project Estimate: $31.6 million;
  - Rehabilitate HVAC systems to support personnel and ongoing operations of critical launch equipment (e.g., monitoring systems, firing and computer rooms);
  - Ensure mission-critical operations (e.g., launch countdowns, controls, communication) are not impacted by system failures;

EXPLORATION COF

  - Replace vital, high-tech equipment that supports launch operations (e.g., Air Handle Units (AHU), computer room air conditioning units, fan coils, chilled water pumps, valves); and
  - Utilize new HVAC systems that save energy and reduce operational costs.

- Replace MAF roof and relocate the fan house:
  - FY 2022 Estimate: $35 million to complete Phase 3 of 5; Total Project Estimate: $174 million;
  - Replace the approximate 1.7 million square foot roof, which houses NASA's primary, large-scale, and environmentally controlled aerospace;
  - Avoid costly delays and potential harm caused by failures and collapses from the existing, deteriorating roof, which is beyond design life and impacted by weather; and
  - Utilize modern materials and methods to greatly enhance sustainability, reduce energy usage and associated costs, and uphold NASA's environmental stewardship goals.

Minor Projects

In FY 2022, Exploration CoF will spend an estimated $35 million to conduct critical repairs, modernization, and upgrades for facilities, infrastructure, and assets that support exploration projects.

- Repair and upgrade VAB Water Distribution System at KSC;
- Renovate the 200-ton bridge crane at KSC’s Rotation, Processing, and Surge Facility (RPSF);
- Repair and revitalize BFF Complex at KSC, including interior renovations; HVAC and security upgrades; replacement of air systems, elevators, and oxygen monitors; and plumbing refurbishment;
- Repair MAF roadways; and
- Replace essential infrastructure within MAF, including fire systems and restrooms.

Facility Planning and Design

In FY 2022, ESDMD and SOMD will conduct facility planning and design activities associated with all projects in the Exploration CoF budget.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

Exploration CoF will continue infrastructure modifications necessary to support SLS and Orion launch operations, along with other exploration missions.

Discrete Projects

- Modify the launch infrastructure at KSC:
  - FY 2023 Estimate: $39.0M complete project funding; Total Project Estimate: $61.6M;
  - Funded jointly with Institutional CoF to ensure success in future mission launches;
  - Upgrade critical systems for nitrogen, temperature and humidity control, air supply, fabrication, and emergency evacuation; and
  - Enable the Artemis campaign and long-distance exploration programs with SLS activities.

- Rehabilitate KSC's LCC HVAC system:
  - FY 2023 Estimate: $28.9 million to fund Phase 2 of 2; Total Project Estimate: $59.4 million;
  - Rehabilitate HVAC systems to support personnel and ongoing operations of critical launch equipment (e.g., monitoring systems, firing and computer rooms);
  - Ensure mission-critical operations (e.g., launch countdowns, controls, communication) are not impacted by system failures;

EXPLORATION COF

- Replace vital, high-tech equipment that supports launch operations (e.g., Air Handle Units [AHU], computer room air conditioning units, fan coils, chilled water pumps, valves); and
- Utilize new HVAC systems that save energy and reduce operational costs.

Minor Projects

In FY 2023, Exploration CoF will spend an estimated $18.3 million to conduct critical repairs, modernization, and upgrades for facilities, infrastructure, and assets that support exploration projects.

- Renovate the interior infrastructure of KSC's Booster Fabrication Facility (Phase 2 of 2);
- Upgrade the HVAC system at KSC's Booster Fabrication Facility for improve efficiency and lower costs (Phase 1 of 2);
- Refurbish the KSC Booster Fabrication Facility complex cranes needed to support the SLS and Artemis campaign Booster flight hardware operations;
- Refurbish the cranes needed to support the SLS and Artemis campaign Booster flight hardware operations in the Michoud Assembly Facility (MAF);
- Upgrade the fire suppression system in buildings 110 and 114 at MAF to improve safety and mission assurance; and
- Upgrade the steam system at MAF to improve reliability in the critical manufacturing plant (Phase 3 of 3).

Facility Planning and Design

In FY 2023, ESDMD and SOMD will conduct facility planning and design activities associated with all projects in the Exploration CoF budget.

SPACE OPERATIONS COF

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**25.2**	**20.5**	**21.3**	**0.0**	**0.0**	**0.0**	**0.0**
Change from FY 2022 Budget Request			**0.8**				
Percent change from FY 2022 Budget Request			**3.9%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

Space CoF provides construction to support Space Communications and Navigation (SCaN), the International Space Station (ISS) program, and the Launch Services Program (LSP). Funds required for the planning and design of out-year programmatic construction remain in the applicable program accounts. Space Operations CoF is managed in collaboration with institutional projects but funded through the former Human Exploration and Operations Mission Directorate (HEOMD), which is now known as the Exploration Systems Development Mission Directorate (ESDMD) and Space Operations Mission Directorate (SOMD).

The Goldstone Solar System Radar (GSSR) facility provides unique capabilities that allow NASA to penetrate deep into space to explore planetary systems and cosmic phenomena.

Space Operations CoF Priorities

Space Operations CoF is prioritized based on mission requirements and the criticality of mission assets.

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

ACHIEVEMENTS IN FY 2021

Discrete Projects

- Completed testing activities for the DEAP project in Madrid and deliver it into operation;
  - Completed construction of DSS-53 facilities; and
  - Transitioned the antennae into the testing and commissioning phase and conduct the geotechnical study for the pedestal remediation project for DSS-54 antenna.
- Completed excavation at the Goldstone Deep Space Communication Complex; and
- Began antenna fabrication work for the new DSS-23 antenna.

SPACE OPERATIONS COF

Minor Projects

- Replaced the beam waveguide antenna drives at Goldstone Deep Space Communication Complex for greater reliability; and
- Upgraded the site-wide uninterruptible power supplies for increased safety and reliability.

Facility Planning and Design

ESDMD and SOMD conducted facility planning and design activities associated with all projects in the Space Operations CoF budget.

WORK IN PROGRESS IN FY 2022

Discrete Projects

- Complete the DEAP BWG antennae at the Goldstone and Canberra Deep Space Communication Complexes:
  - FY 2022 Estimate: $12.5 million to complete Phase 4 of 8; Total Project Estimate: $93.7 million;
  - Complete construction and start operations of DSS-53 antenna at the Madrid Deep Space Communication Complex, enabling the array of four antennae for an enhanced aperture;
  - Complete the DSS-23 antenna pedestal at the Goldstone Deep Space Communication Complex, along with other critical infrastructure including flood controls, water, and HVAC systems, electrical, surveillance, and fire detection systems; and
  - Enable both radio frequency and optical communications for deep space exploration missions.

Minor Projects

In FY 2022, Space Operations CoF will spend an estimated $8 million to conduct repairs, modernization, and upgrades to ensure the safe and reliable continued operations of vital communication and monitoring systems. Repairs and upgrades will address crucial systems in current assets, including electrical and fire systems, accessibility and code compliance, and other necessary refurbishment.

- Upgrade the switchgear to provide redundancy and ensure reliability at the Apollo site;
- Install an additional underground backup power feed from the Mars site to the Apollo site to support vital communications during long-term expeditions; and
- Expand the underground fiber optic cable from the Mars site to the Apollo site at the Goldstone Deep Space Communication Complex to ensure continuous connectivity during missions.

Facility Planning and Design

ESDMD and SOMD will conduct facility planning and design activities associated with all projects in the Space Operations CoF budget.

SPACE OPERATIONS COF

KEY ACHIEVEMENTS PLANNED FOR FY 2023

Discrete Projects

- Complete the DEAP BWG antennae at the Goldstone and Canberra Deep Space Communication Complexes:
  - FY 2023 Estimate: $7.1 million to complete Phase 5 of 9; Total Project Estimate: $132.8 million;
  - Complete construction and start operations of DSS-53 antenna at the Madrid Deep Space Communication Complex, enabling the array of four antennae for an enhanced aperture;
  - Complete the DSS-23 antenna pedestal at the Goldstone Deep Space Communication Complex, along with other critical infrastructure including flood controls, water, and HVAC systems, electrical, surveillance, and fire detection systems; and
  - Enable both radio frequency and optical communications for deep space exploration missions.

Minor Projects

In FY 2023, Space Operations CoF will spend an estimated $14.2 million to conduct repairs, modernization, and upgrades to ensure the safe and reliable continued operations of vital communication and monitoring systems. Repairs and upgrades will address crucial systems in current assets, including electrical and fire systems, accessibility and code compliance, and other necessary refurbishment.

- Modify the DSS-14 Antenna and the Goldstone Solar System Radar facility for improved, long-range exploration and scientific missions;
- Build redundant data and signal processing centers to ensure the security and storage of vital mission data gathered during explorational and scientific missions; and
- Replace the fire detection system at Goldstone for improved site operations.

Facility Planning and Design

ESDMD and SOMD will conduct facility planning and design activities associated with all projects in the Space Operations CoF budget.

ENVIRONMENTAL COMPLIANCE AND RESTORATION

FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**58.1**	**74.7**	**76.2**	**79.4**	**81.0**	**82.7**	**82.7**
Change from FY 2022 Budget Request			**1.5**				
Percent change from FY 2022 Budget Request			**2.0%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

NASA maintains a high standard for environmental stewardship and cleanup connected to its mission work, like propellant and fuel testing seen here at the Mississippi Test Facility (MTF).

NASA’s Environmental Compliance and Restoration (ECR) program cleans up hazardous materials and waste products released to the surface or groundwater at current and former NASA installations or associated facilities. Over the years, NASA activities have contributed to environmental problems. It is the Agency's ethical and legal responsibility to address hazardous pollutants and environmental impacts.

ECR activities include projects, studies, assessments, investigations, sampling, plans, designs, construction, engineering, program support, monitoring, and regulatory oversight. Funding also covers land acquisitions required to ensure operation of remedial treatment processes and facilities as part of remediation and cleanup measures.

ECR Priorities

Cleanup, studies, and other activities related to environmental stewardship are prioritized based on a combination of legal and statutory requirements, assessed risk, and mission requirements. ECR’s overarching goal is to ensure public health, restore natural resources, and reduce NASA’s environmental burden. ECR activities are conducted in each of the following high priority areas:

- Conduct cleanup activities, including soil removal and demolition, to eliminate harmful substances or materials and reduce environmental impacts;
- Ensure the public and the NASA workforce are not exposed to harmful chemicals from current or previous mission activities through continuous monitoring, treatment, and reporting;
- Provide policies, guidance, communications, strategy, and planning support to stakeholders, including centers, local governments, Tribal nations, regulatory entities, and other Government agencies; and
- Provide critical equipment needed for the continued monitoring, treatment, and analysis of harmful substances and contaminants.

ENVIRONMENTAL COMPLIANCE AND RESTORATION

EXPLANATION OF MAJOR CHANGES IN FY 2023

None.

ACHIEVEMENTS IN FY 2021

ECR will continue cleanup activities at all NASA centers, with priority given to protecting health and conforming to environmental regulations and statutory requirements. ECR activities vary by site and restoration phase. ECR funded activities include contaminant site planning, sampling, investigation, modelling, remedial design, remedial construction, operations and maintenance, long term monitoring, land use maintenance, demolition, and waste disposal, as well as compliance related projects with an Agency impact. Currently NASA is managing over 130 restoration sites of varying scope and in various phases of completion. Due to the complexity of removing hazardous substances from soil and groundwater, many of these sites will see some form of active restoration or monitoring activity for decades. Annually, ECR supports new or continued activity at many of these sites. Example ECR funded activities include:

- Continued to operate groundwater treatment facilities to remove contaminants across the Agency;
- Began abatement and demolition of Bravo Test Stands and Control House at Santa Susana Field Lab (SSFL);
- Operated and maintained groundwater treatment systems at JPL and continued to operate the Lincoln Avenue and Monk Hill drinking water treatment systems;
- Completed contaminated soil removal at MSFC and implement interim actions to address sources of groundwater contamination;
- Initiated remediation fieldwork at the Erie County Conservation League Firing Range at GRC;
- Sampled soil, groundwater, surface water, and sediments at various centers to verify PFAS contamination and determine whether further action is warranted;
- Completed cleanup of Area D at SSC and removed the extraction and monitoring wells, demolished the support building, and removed pump and treat equipment;
- Remediated groundwater pollutants from the JSC B 358 Surface Impoundment Area, formerly used for treatment of process wastewater from the adjacent Energy Systems Testing Area;
- Completed soil vapor delineation sampling at Quiet Engine Test Stand and initiated feasibility study at GRC to access impacts of any harmful contaminants and necessary remediation;
- Maintained a groundwater treatment system located at Area South of Facility 516 Operations at KSC;
- Completed supplemental soil and soil vapor sampling for Solid Waste Management Unit 10 at WFF;
- Initiated work on a Conceptual Site Model at White Sands Test Facility (WSTF) to identify opportunities to optimize plume capture and contaminant removal activities;
- Provided regulatory risk analysis and communication support Agency-wide;
- Resumed construction of recloser and power meter for Plume-Front treatment system at WSTF;
- Developed an Agency Climate Action Plan in accordance with Executive Order 14008, Tackling the Climate Crisis at Home and Abroad to integrate NASA's climate change adaptation and climate resilience across Agency programs; and
- Initiated Tribal Consultation Plan development in compliance with Executive Order and Presidential Memorandum requirements.

ENVIRONMENTAL COMPLIANCE AND RESTORATION

WORK IN PROGRESS IN FY 2022

ECR will continue cleanup activities at all NASA centers, with priority given to protecting health and conforming to environmental regulations and statutory requirements. In addition to the specific actions below, the ECR program continues to implement site wide restoration activities, contaminated groundwater cleanup, and investigate soil contamination Agency-wide:

- Continue to operate groundwater treatment facilities to remove contaminants across the Agency;
- Continue to demolish SSFL Bravo Test Stands and begin demolition of Coca Test Stands;
- Implement pump and treat remedy and Groundwater Extraction and Treatment System optimization, design, well-head modifications, pipeline reconfiguration at SSFL;
- Continue to operate and maintain groundwater treatment systems at JPL and continue to operate the Lincoln Avenue and Monk Hill drinking water treatment systems;
- Complete debris removal and initiate Remedial Design at Disposal Area 2A at GRC;
- Complete remediation of Quiet Engine Test Stand at GRC and submit closeout report;
- Continue to investigate and cleanup contamination at KSC, including the installation of new groundwater treatment systems, removal of contaminated soils, investigation of potential contamination, and sampling over 700 monitoring wells;
- Continue MSFC site wide restoration activities including implementing interim actions to address the groundwater plume operable unit source areas;
- Complete the closure activities and receive a "No Further Action" notification from the regulator for Area A at SSC;
- Complete the construction of Plume-Front recloser and power meter at WSTF;
- Provide regulatory risk analysis and communication support;
- Complete Vertical Process Facility air sparge system abandonment at KSC;
- Implement the emulsified zero-valent iron Phase 3 enhanced remediation project at SSC;
- Execute and update the Agency Climate Action Plan in accordance with Executive Order 14008, Tackling the Climate Crisis at Home and Abroad to integrates NASA's climate change adaptation and climate resilience across Agency programs; and
- Continue development of NASA Tribal Consultation Plan.

KEY ACHIEVEMENTS PLANNED FOR FY 2023

ECR will continue cleanup activities at all NASA centers, with priority given to protecting health and conforming to environmental regulations and statutory requirements. In addition to the specific actions below, the ECR program will continue to implement site wide restoration activities, contaminated groundwater cleanup, and investigate soil contamination Agency-wide:

- Continue to operate groundwater treatment facilities to remove contaminants across the Agency;
- Continue to demolish SSFL Bravo and Coca Test Stands;
- Implement soil removal action at South Wallops Island;
- Continue to investigate and cleanup contamination at KSC, including the installation of new groundwater treatment systems, removal of contaminated soils, investigation of potential contamination, and sampling over 700 monitoring wells;
- Continue MSFC site wide restoration activities including implementing interim actions to address the groundwater plume operable unit source areas;

ENVIRONMENTAL COMPLIANCE AND RESTORATION

- Continue to operate and maintain groundwater treatment systems at JPL and continue to operate the Lincoln Avenue and Monk Hill drinking water treatment systems;
- Continue site wide restoration activities, contaminated groundwater cleanup, and investigate soil contamination at WSTF;
- Conduct Remedial Investigation/Feasibility Study at Engine Research Building at GRC;
- Conduct feasibility study and proposed plan at GRC's Disposal Area 2A & 2B;
- Provide regulatory risk analysis and communication support; and
- Execute and update the Agency Climate Action Plan in accordance with Executive Order 14008, Tackling the Climate Crisis at Home and Abroad to extend NASA's climate resilience across the Agency.

INSPECTOR GENERAL

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**44.2**	**46.0**	**48.4**	**49.4**	**50.4**	**51.4**	**52.4**

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

INSPECTOR GENERAL

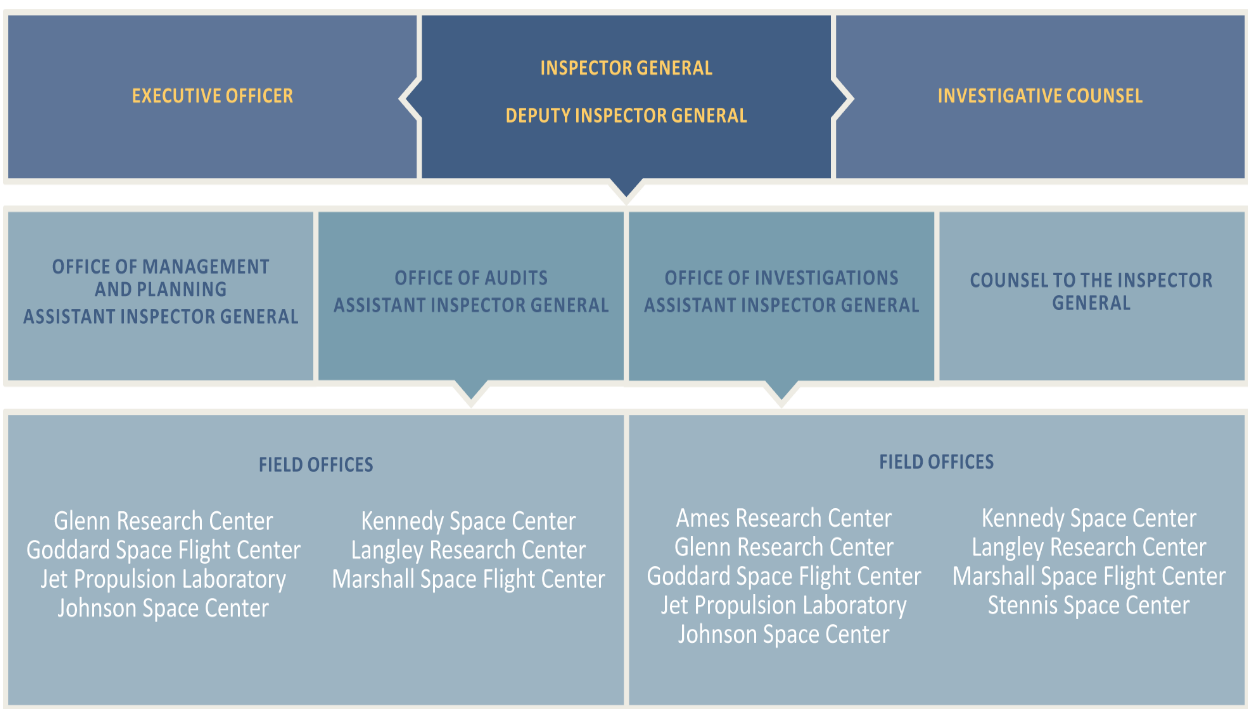
FY 2023 Budget

Budget Authority (in $ millions)	Op Plan FY 2021	Request FY 2022	Request FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Total Budget	**44.2**	**46.0**	**48.4**	**49.4**	**50.4**	**51.4**	**52.4**
Change from FY 2022 Budget Request			**2.4**				
Percent change from FY 2022 Budget Request			**5.2%**				

FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Operating Plan, December 2021.

Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request.

The mission of the Office of Inspector General (OIG) is to improve NASA's programs and operations through independent and objective oversight. OIG conducts audits, investigations, and reviews of NASA programs to prevent and detect fraud, waste, abuse, and mismanagement, and assists NASA leaders and Congress in promoting economy, efficiency, and effectiveness through its oversight role. OIG's operational offices consist of the Office of Audits (OA), Office of Investigations (OI), Office of Counsel to the Inspector General, and Office of Management and Planning (OMP).



OIG Organizational Chart

OA conducts independent and objective audits of NASA programs, projects, operations, and contractor activities, and oversees the work of the independent public accounting firm that conducts the Agency's annual financial statement audit. OA targets high-risk areas and top management challenges to assist NASA's efforts to achieve its space exploration, scientific discovery, space technology, and aeronautics goals. OIG audits provide fact-based analysis with actionable recommendations that helps NASA improve its operations and achieve its space exploration, scientific, and aeronautics goals more effectively and efficiently.

OI investigates allegations of cybercrime, fraud, waste, abuse, and misconduct related to NASA programs, operations, and resources. OI refers its findings to the Department of Justice (DOJ) for criminal prosecution and civil litigation or to NASA management for administrative action. OI also develops recommendations for NASA management that aim to reduce the Agency's vulnerability to criminal activity, misconduct, and administrative inefficiency. OI's caseload includes investigations of suspected false claims submitted by NASA contractors, product substitution and counterfeit parts, and conflict of interest cases that involve NASA employees placing private gain before public service.

Office of Counsel to the IG provides legal advice and assistance to OIG managers, auditors, and investigators. The office serves as counsel for administrative litigation and assists the DOJ when the OIG is part of the prosecution team, or when the OIG is a witness or defendant in legal proceedings. In addition, the office is responsible for educating Agency employees about prohibitions on retaliation for protected disclosures, and about rights and remedies for protected whistleblower disclosures.

OMP provides financial, procurement, human resources, administrative, and IT services and support to OIG staff. OMP ensures state-of-the-art IT system capabilities for the OIG, advises the Inspector General and OIG senior management on budget issues and human resources staffing matters, directs OIG internal management and support operations, and oversees development and adherence to management policies and procedures.

BUDGET REQUEST OVERVIEW

For FY 2023, the NASA OIG requests a total of $48.4 million in direct appropriations to support the work of auditors, investigators, analysts, specialists, lawyers, and support staff at NASA Headquarters in Washington, DC, and 12 other locations throughout the United States.

The FY 2023 budget will enable the OIG to continue to deliver impactful audits and investigations. In addition, this budget request supports statutorily mandated oversight activities, such as the Agency's Consolidated Financial Statements Audit and the Federal Information Security Management Act (FISMA) audit.

FY 2023 BUDGET REQUEST (in millions):	FY 2022*	FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
BUDGET BASELINE	46.0	47.6	$49.4	$50.4	$51.4	$52.4
PROGRAM CHANGE		0.8	0.0	0.0	0.0	0.0
BUDGET REQUEST	**$46.0**	**$48.4**	**$49.4**	**$50.4**	**$51.4**	**$52.4**
PERSONNEL	$37.9	$40.2	$41.0	$41.8	$42.7	$43.5
TRAVEL	0.7	0.7	0.7	0.7	0.7	0.8
OPERATIONS**	7.4	7.5	7.7	7.9	8.0	8.1
OIG REQUEST	**$46.0**	**$48.4**	**$49.4**	**$50.4**	**$51.4**	**$52.4**
FTE SUPPORTABLE	**187**	**190**	**190**	**190**	**190**	**190**

** Full-year appropriations for FY 2022 were not enacted at the time this budget was prepared. Therefore, the FY 2022 column reflects the FY 2022 President's Budget Request for the OIG.*

*** In accordance with Public Law 110-409, the Inspector General Reform Act of 2008, the Inspector General certifies that $0.4M for staff training and $0.2M to support the Council of the Inspectors General on Integrity and Efficiency satisfy all known training requirements and planned contributions to the Council.*

OIG's FY 2023 budget request allocation is as follows:

- $40.2 million (83 percent) for personnel and related costs, including salaries, benefits, monetary awards, and government contributions for Social Security, Medicare, health and life insurance, retirement, and the Thrift Savings Plan, which includes increased rates for retirement contributions;
  - Salaries include pay adjustments for civilian employees in 2023 (one quarter at +2.7 percent and three quarters at +4.6 percent), plus the required additional 25 percent law enforcement availability pay for OIG's approximately 55 criminal investigators.
- $3.4 million (7 percent) for the statutorily required annual audits of the Agency's financial statements and FISMA;
- $0.7 million (1.5 percent) for employee travel, per diem, and related expenses;
- $0.4 million (1 percent) for training and staff development; and
- $3.7 million (7.5 percent) for operational procurements including equipment, vehicles, special equipment for criminal investigators, transit subsidies, and information technology equipment unique to the OIG.

EXPLANATION OF MAJOR CHANGES IN FY 2023

BASE ADJUSTMENTS AND PROGRAM CHANGES

For FY 2023, the OIG requests a total of $48.4 million in direct appropriations with two-year funding authority.

FY 2023 BUDGET REQUEST (in millions)	
FY 2022 President's Budget Submission	$46.0
Base Adjustments	
Personnel and related costs	$1.5
Operations (Procurements Annualizations/Inflation)	$0.4
Travel Reductions	$(0.3)
FY 2023 CURRENT SERVICES	**$47.6**
Other Program Changes - FISMA Audit Contract	$0.8
FY 2023 REQUEST	**$48.4**

BASE ADJUSTMENTS

The OIG is a personnel-driven organization with salaries, employee benefits and other related costs representing 83 percent of the total budget. This request includes a 4.6 percent increase in 2023 base pay for civilian and Law Enforcement Officer (LEO) employees. Consequently, any reductions or freezes to the OIG's budget directly impact the staffing needed to carry out the oversight mission.

During FY 2021 and FY 2022, the OIG has been utilizing more information technology tools, which has allowed staff to perform more investigative and audit activities remotely, while still performing at the highest standards needed to accomplish the mission. This has resulted in increases of procurement costs, which have been offset by reductions in travel. The OIG plans to continue using many of these virtual resources resulting in travel savings.

PROGRAM INCREASE - FISMA

This budget request requests an additional $800,000 to contract with a private firm to conduct the annually required FISMA audit to help assess the integrity of NASA information technology (IT) systems. The OIG has consistently identified "Managing and Mitigating Cybersecurity Risk" as a top management challenge for the Agency. The OIG's 2020 Management Challenges report noted that in addition to poor FISMA scores, NASA's darknet risk score ranks 7th highest in the Federal Government, just behind the military. The OIG's 2021 Management Challenges report noted that NASA's information security program showed some improvement, but still fell short of the Office of Management and Budget's watermark for a program to be considered effective. The ability to conduct comprehensive audits of Agency programs and systems requires staff with specialized IT skills. However, due to staffing constraints, our ability to perform additional IT audits in high-risk areas has been limited while we deploy audit staff with the necessary IT skills to meet the annual FISMA requirement.

Similar to outsourcing the annual Financial Statement Audit with a public accounting firm, the OIG seeks to contract a public accounting firm to conduct the FISMA audit in FY 2022 using realized cost savings from salary lapse and lower than anticipated travel costs. Contracting out the FISMA audit would allow for the 3-4 full-time equivalents who are primarily assigned to FISMA to be re-deployed to work on more critical projects. Furthermore, the additional funding provided in the prior year budget request would allow us to hire two experienced IT auditors. We believe that these strategic hires, in combination with contracting out the annual FISMA work, will provide the OIG with the needed bandwidth to exercise additional and much-needed oversight over NASA's IT systems.

PROPOSED CHANGE IN FUNDING AUTHORITY

In Public Law 116-260, Consolidated Appropriations Act, 2021, the OIG received $500,000 of 2-year funding to help with the execution of the budget in alignment with NASA's end-of-year close-out procedures, as no other NASA mission has one-year authority. Fully aligning the entire OIG's appropriation with the rest of NASA would provide additional latitude in executing OIG's funding and improving resource planning. For these reasons, the OIG is requesting two-year budget authority for its total direct appropriations in FY 2023. This funding authority will also provide more certainty in funding and efficiencies in hiring for an organization that is 83 percent personnel driven. It will allow the OIG to streamline business processes and other financially related year-end processes within NASA's centralized systems and budgetary framework to execute the oversight mission more efficiently.

Proposed New Appropriations Language for FY 2023

For necessary expenses of the Office of Inspector General in carrying out the Inspector General Act of 1978, $48,400,000, to remain available until September 30, 2024.

ACHIEVEMENTS IN FY 2021

During this reporting period, the NASA OIG operated exclusively in a telework mode due to the COVID-19 pandemic that closed NASA facilities, with the exception of mission-critical work. Nevertheless, NASA OIG auditors, investigators, attorneys, and support staff continued to conduct impactful, independent, and comprehensive oversight of NASA programs and personnel.

In FY 2021, the OIG issued 17 audit products containing 112 recommendations for improvement and identifying $246,060 in questioned costs for NASA, with an additional $6 to $7 million in potential monetary savings. Audit products included reports examining NASA's management of:

- Construction of facilities;
- Development of next-generation spacesuits;
- Cooperative agreements with Universities Space Research Association;
- COVID-19 impacts on major programs and projects;
- Efforts to mitigate orbital debris;
- Hazardous materials;
- The Gateway program for Artemis missions; and
- The readiness of NASA's acquisitions.

In FY 2021, OI investigated a wide variety of criminal and administrative matters involving procurement fraud, theft, counterfeit parts, ethics violations, and computer intrusions leading to more than $7.6 million in criminal, civil, and administrative penalties and settlements with approximately $1.5 million of these funds returned directly to NASA. OI's efforts in FY 2021 resulted in 14 indictments, 15 convictions/sentences, 12 civil settlements, 29 administrative actions, and 31 suspensions or debarments. Examples of OI's work over the past year include:

- As the result of a multi-year, multi-agency investigation, the co-owner of a Delaware company pleaded guilty to wire fraud for intentionally making false representations in grant proposals and payment requests to several Government agencies, including NASA. The co-owner was sentenced to two years of probation to include one year of home confinement and was ordered to pay a $50,000 fine. The co-owner also entered into a civil settlement agreement whereby he paid $700,000 to the Federal Government.

- As the result of a joint investigation by NASA OIG, the National Institutes of Health, and the United States Air Force, a Kansas engineering company agreed to a civil settlement of $672,352 to resolve allegations that it submitted false claims to obtain grant funds from the Small Business Innovation Research (SBIR) and Small Business Technology Transfer programs. The investigation determined that between April 2012 and July 2015, the company received small business funding for which it was ineligible.
- As the result of a joint investigation by NASA OIG and the United States Department of Energy Office of Inspector General, a Wyoming small business agreed to pay damages of $557,684 in a civil settlement to resolve allegations that it accepted SBIR funding to which it was not entitled from NASA, the United States Department of Energy, and the United States Department of Health and Human Services.
- A New York company agreed to a settlement of $490,000 to resolve allegations under the civil False Claims Act that it did not satisfy ownership and control requirements under the SBIR program. The company was ineligible for SBIR awards from NASA and the Department of Defense due to the involvement of foreign investors.
- In December 2020, a settlement was finalized on behalf of NASA and the United States Department of Energy (DOE) with the principal investigator of several SBIR contracts. The individual settled for $28,500, bringing the total recovery to $402,684. The investigation stemmed from an initiative in which NASA OIG determined the company made false representations and certifications to obtain the contracts.
- A former NASA contractor agreed to a civil settlement of $250,000 following a NASA OIG investigation of conspiracy and wire fraud allegations. The contractor misrepresented itself as a woman-owned small business to gain an unfair competitive advantage for subcontracts at Kennedy Space Center.
- Following an investigation by NASA OIG, a former contractor agreed to a civil settlement of $122,452 to resolve allegations of false statements in proposals submitted to NASA, the National Science Foundation, and the DOE's SBIR programs.
- In August 2021, a Federal jury convicted the former general manager of a Florida small business on multiple counts of conspiracy and wire fraud for his role in misrepresenting the company as a woman-owned small business (WOSB) in a scheme to secure Government contracts. The company fraudulently received more than $6 million in contract payments, to include $1 million during the former general manager's tenure. The former general manager will be sentenced in December 2021 and is the fourth employee convicted in the fraud scheme.
- A former SBIR company agreed to a civil settlement of $192,586 for charging for work by individuals who performed little or no activity under the contracts and for substituting contract personnel without permission. As part of its settlement, the company agreed to implement enhanced compliance measures to resolve claims arising from its questionable administration of Federal grants and contracts.

- Three executives of a Titusville, Florida, engineering company pleaded guilty to conspiracy to commit wire fraud and misprision of felony charges related to a 22-year conspiracy to defraud NASA and its contractors by misrepresenting the company as a WOSB. As a result of the scheme, the company was fraudulently awarded more than $84 million in NASA contracts. The CEO was ordered to pay $893,062 as part of a criminal forfeiture; sentencing will occur in September and October 2021. The company had previously agreed to a $250,000 civil settlement.
- Following a joint investigation by the NASA OIG and the Los Angeles County District Attorney's Office, the former mayor of Palmdale, California, pleaded guilty and was sentenced for his part in a scheme by a contractor to systematically misuse NASA funds. The former mayor was sentenced to 24 months of probation and ordered to pay $189,800 in restitution to NASA. A former executive at the company was debarred from working with the Federal Government following a prior criminal conviction for her part in the scheme.

WORK IN PROGRESS AND KEY ACHIEVEMENTS PLANNED FOR FY 2023

In the first three months of FY 2022, the OIG has issued audit reports titled NASA's Fiscal Year 2020 Digital Accountability and Transparency Act Submission, Management of the Artemis Missions and Management of International Space Station, and Efforts to Commercialize Low Earth Orbit. Additionally, the OIG issued the mandated Audit of NASA's Fiscal Year 2021 Financial Statements and Evaluation of NASA's Information Security Program under the Federal Information Security Modernization Act for Fiscal Year 2021.

During the remainder of the fiscal year, the OIG will examine NASA's efforts to encourage commercialization of low-Earth orbit, management of its astronaut corps, multi-mission cost estimating and reporting practices, and contracting and performance management for programs, including the Mobile Launcher 2, the Volatiles Investigating Polar Exploration Rover (VIPER) project, and the Radioisotope Power Systems Program. The OIG continues to provide oversight in the information technology domain, with an audit of NASA's Insider Threat Program. Additionally, the OIG has an ongoing review of NASA's efforts to advance diversity, equity, inclusion, and accessibility, as well as an audit on the Agency's ability to provide stakeholders with information to help predict, prepare for, and recover from natural disasters. Ongoing OI work includes proactive initiatives designed to identify acquisition and procurement fraud schemes. Additionally, representatives from both OI and OA are working together to use OIG's advanced data analytics capabilities to help identify indicators of potentially fraudulent activity.

In FY 2023, OIG will continue to focus its audit work on NASA's top management and performance challenges identified in our November 2021 report. Specifically, OIG plans to undertake work in the following areas:

- Returning humans to the Moon;
- Improving management of major projects;
- Sustaining a human presence in low-Earth orbit;
- Managing and mitigating cybersecurity risk;
- Improving oversight of contracts, grants, and cooperative agreements;
- Attracting and retaining a highly skilled and diverse workforce;
- Managing NASA's outdated infrastructure and facilities; and
- Managing the impacts of COVID-19 on NASA's mission and workforce.

OIG will also continue oversight in a variety of Financial Management and Quality Control areas to include:

- Improper Payments Information Act compliance;
- Desk and quality control reviews of selected single audit reporting packages;
- Oversight of Financial Statement Audit;
- Risk assessment of purchase and travel card programs;
- Geospatial Data Act;
- Management of non-reimbursable agreements; and
- Federal Information Security Modernization Act.

As NASA continues to work toward landing the first woman and person of color on the Moon, with the eventual goal of landing humans on Mars, additional OIG funding will enable enhanced oversight of major NASA projects.

From an investigative perspective, the FY 2023 request will continue support for investigations of cybercrime, fraud, waste, abuse, and misconduct related to NASA programs, projects, personnel, operations, and resources.

Given the important role of NASA's contracting practices in Agency missions, most of OIG's proactive initiatives focus on acquisition activities that are susceptible to procurement fraud schemes. Examples of ongoing, proactive initiatives that will continue to be active throughout FY 2023 include the following:

- A project to monitor and aggregate data related to NASA's Artemis campaign in an attempt to identify indications of fraud on the part of prime contractors and subcontractors;
- A project with OIG's Audit component to conduct incurred cost audits of specific NASA subcontractors;
- A Criminal and Cyber Threat Intelligence (CaCTI) project that will identify sensitive procurement information and other critical data that may have been improperly exfiltrated from NASA computer systems; and
- Multiple initiatives commenced to identify, detect, and deter fraud involving grant and contract recipients who surreptitiously receive significant financial support from foreign governments and/or fail to identify potential foreign-based conflicts of interest in violation of NASA policies and/or Federal law.

Finally, in FY 2023 OIG intends to continue to place additional emphasis on Pandemic Response Accountability Committee (PRAC) initiatives, that include Coronavirus Aid, Relief and Economic Security (CARES) Act and Paycheck Protection Program (PPP) investigations. We will also continue to develop other proactive initiatives designed to identify procurement fraud and antitrust crimes (such as bid-rigging conspiracies and related fraudulent schemes) that undermine competition in Government procurement, grant, and program funding.

Supporting Data

FUNDS DISTRIBUTION

DISCRETIONARY BUDGET REQUEST BY MISSION BY NASA CENTER

Budget Authority ($ in millions)	FY 2023*
Deep Space Exploration Systems	34.3
Space Technology	57.8
Space Operations	14.9
Science	229.5
Aeronautics	187.9
STEM Engagement	3.2
Construction and Environmental Compliance and Restoration	3.5
Safety, Security, and Mission Services	196.2
Ames Research Center (ARC) Total	**727.3**
Deep Space Exploration Systems	0.0
Space Technology	21.8
Space Operations	0.1
Science	22.0
Aeronautics	181.8
STEM Engagement	11.5
Construction and Environmental Compliance and Restoration	7.8
Safety, Security, and Mission Services	64.5
Armstrong Flight Research Center (AFRC) Total	**309.6**
Deep Space Exploration Systems	152.9
Space Technology	86.2
Space Operations	90.3
Science	49.1
Aeronautics	215.2
STEM Engagement	8.8
Construction and Environmental Compliance and Restoration	15.3
Safety, Security, and Mission Services	212.5
Glenn Research Center (GRC) Total	**830.3**
Deep Space Exploration Systems	6.6
Space Technology	179.9
Space Operations	169.6
Science	3030.8
Aeronautics	0.0
STEM Engagement	10.3
Construction and Environmental Compliance and Restoration	62.5
Safety, Security, and Mission Services	388.9
Goddard Space Flight Center (GSFC) Total	**3,848.6**

FUNDS DISTRIBUTION

Budget Authority ($ in millions)	FY 2023*
Deep Space Exploration Systems	12.0
Space Technology	52.3
Space Operations	184.7
Science	1556.9
Aeronautics	0.0
STEM Engagement	2.1
Construction and Environmental Compliance and Restoration	27.7
Safety, Security, and Mission Services	9.4
Jet Propulsion Laboratory (JPL/NMO) Total	**1,845.0**
Deep Space Exploration Systems	2252.9
Space Technology	55.0
Space Operations	3241.9
Science	305.6
STEM Engagement	13.1
Construction and Environmental Compliance and Restoration	20.0
Safety, Security, and Mission Services	350.7
Johnson Space Center (JSC) Total	**6,239.2**
Deep Space Exploration Systems	879.0
Space Technology	73.4
Space Operations	193.6
Science	267.7
Aeronautics	0.0
STEM Engagement	22.6
Construction and Environmental Compliance and Restoration	102.4
Safety, Security, and Mission Services	358.0
Kennedy Space Center (KSC) Total	**1,896.7**
Deep Space Exploration Systems	18.7
Space Technology	54.2
Space Operations	6.4
Science	322.6
Aeronautics	292.4
STEM Engagement	30.6
Construction and Environmental Compliance and Restoration	11.5
Safety, Security, and Mission Services	266.2
Langley Research Center (LaRC) Total	**1,002.6**
Deep Space Exploration Systems	3309.3
Space Technology	190.4
Space Operations	137.7
Science	287.3
Aeronautics	0.0
STEM Engagement	3.6
Construction and Environmental Compliance and Restoration	15.0
Safety, Security, and Mission Services	532.9
Marshall Space Flight Center (MSFC) Total	**4,476.1**

FUNDS DISTRIBUTION

Budget Authority ($ in millions)	**FY 2023***
Deep Space Exploration Systems	771.4
Space Technology	663.6
Space Operations	194.9
Science	1916.7
Aeronautics	94.2
STEM Engagement	20.5
Construction and Environmental Compliance and Restoration	158.6
Safety, Security, and Mission Services	776.9
Office of Inspector General	48.4
NASA Headquarters (HQ) and Inspector General (IG) Total	**4,645.4**
Deep Space Exploration Systems	41.1
Space Technology	3.2
Space Operations	32.2
Science	0.1
Aeronautics	0.0
STEM Engagement	23.9
Construction and Environmental Compliance and Restoration	0.0
Safety, Security, and Mission Services	52.5
Stennis Space Center (SSC) Total	**153.0**
	25,973.8

**Totals may not add due to rounding*

NOTE: Funds will not be fully distributed to the centers until after final acquisition decisions are made. Thus, FY 2023 allocations by center should not be considered final or directly comparable to prior year allocations.

CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION

NASA's workforce continues to be one of its greatest assets for enabling missions in space and on Earth. The Agency remains committed to applying this asset to benefit society, address contemporary environmental and social issues, lead or participate in emerging technology opportunities, collaborate and strengthen the capabilities of commercial partners, and communicate the challenges and results of Agency programs and activities. The civil service staffing levels funded in the FY 2023 Budget continues to support NASA's scientists, engineers, researchers, managers, technicians, and business operations workforce. It includes civil service personnel at NASA centers, Headquarters, and NASA-operated facilities.

NASA continually assesses and adjusts the mix of skills in its workforce to address changing mission priorities, leveraging industry and academic partnerships, and on and near-site support contracts to operate effectively in a leaner fiscal environment. A knowledgeable and well-trained civil service workforce is critical for conducting mission-essential work in research and technology. The Agency will apply the valued civil service workforce to priority mission work, adjusting the mix of skills where appropriate. Centers will explore cross-mission retraining opportunities for employees whenever possible, offer targeted buyouts in selected surplus skill areas, and continue to identify, recruit, and retain a multi-generational workforce of employees who possess skills critical to the Agency.

CIVIL SERVICE FULL-TIME EQUIVALENT (FTE) DISTRIBUTION BY CENTER – DIRECT FUNDED

	Actual	Estimate	Request				
	FY 2021	**FY 2022**	**FY 2023**	**FY 2024**	**FY 2025**	**FY 2026**	**FY 2027**
ARC	1,230	1,187	1,160	1,160	1,160	1,160	1,160
AFRC	473	528	525	525	525	525	525
GRC	1,450	1,445	1,528	1,528	1,528	1,528	1,528
GSFC	2,981	2,968	2,948	2,948	2,948	2,948	2,948
JSC	2,832	3,119	2,992	2,992	2,992	2,992	2,992
KSC	1,995	2,080	2,012	2,012	2,012	2,012	2,012
LaRC	1,730	1,741	1,780	1,780	1,780	1,780	1,780
MSFC	2,243	2,436	2,333	2,333	2,333	2,333	2,333
SSC	259	248	257	257	257	257	257
HQ	1,215	1,288	1,355	1,355	1,355	1,355	1,355
NSSC	8	-	-	-	-	-	-
NASA Total*	**16,416**	**17,040**	**16,890**	**16,890**	**16,890**	**16,890**	**16,890**
OIG	171	187	190	190	190	190	190

**Totals may not add due to rounding.*

NOTE: FY 2022 estimates are based on full year CR amounts. Funds will not be fully distributed to Centers until after final acquisition decisions are made. Thus, Center FY 2023 allocations should not be considered final or directly comparable to prior year allocations.

CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION

CIVIL SERVICE FULL-TIME EQUIVALENT (FTE) DISTRIBUTION BY CENTER – REIMBURSABLE FUNDED

	Actual	Estimate	Request				
	FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
ARC	25	22	22	22	22	22	22
AFRC	29	15	15	15	15	15	15
GRC	8	3	3	3	3	3	3
GSFC	179	219	219	219	219	219	219
JSC	29	-	-	-	-	-	-
KSC	13	1	1	1	1	1	1
LaRC	14	15	15	15	15	15	15
MSFC	41	-	-	-	-	-	-
SSC	6	25	25	25	25	25	25
HQ	7	-	-	-	-	-	-
NSSC	155	169	165	165	165	165	165
NASA Total*	**507**	**469**	**465**	**465**	**465**	**465**	**465**
OIG	7	7	7	7	7	7	7

**Totals may not add due to rounding.*

NOTE: FY 2022 estimates are based on full year CR amounts. Funds will not be fully distributed to Centers until after final acquisition decisions are made. Thus, Center FY 2023 allocations should not be considered final or directly comparable to prior year allocations.

CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION

FY 2023 FTE DISTRIBUTION BY ACCOUNT BY CENTER

	Deep Space Exploration Systems	Space Operations	Space Technology	Science	Aeronautics	STEM Engagement	Safety, Security, and Mission Services	Reimbursable / Working Capital Fund**	Inspector General	NASA-Funded Total	Agency TOTAL
ARC	50	34	104	203	276	2	491	22		1,160	1,182
AFRC	-	-	14	90	222	2	197	15		525	540
GRC	180	122	194	83	433	6	510	3		1,528	1,531
GSFC	13	135	124	1,329	-	5	1,342	219		2,948	3,167
JSC	831	1,212	69	65	-	7	808	-		2,992	2,992
KSC	579	496	66	21	-	4	846	1		2,012	2,013
LaRC	78	16	125	210	540	5	806	15		1,780	1,795
MSFC	890	170	192	243	-	4	834	-		2,333	2,333
SSC	48	38	10	-	-	2	159	25		257	282
HQ	34	37	24	159	22	17	1,062	-		1,355	1,355
NSSC								165		-	165
NASA Total*	**2,703**	**2,260**	**922**	**2,403**	**1,493**	**54**	**7,055**	**465**	**-**	**16,890**	**17,355**
OIG	-	-	-	-	-	-	-	7	190	190	197

**Totals may not add due to rounding*

***Includes 165 FTE funded by Working Capital Fund; and 300 FTE funded by reimbursable customers*

NOTE: Funds will not be fully distributed to Centers until after final acquisition decisions are made. Thus, Center FY 2023 allocations should not be considered final or directly comparable to prior year allocations.

WORKING CAPITAL FUND

NASA established the Working Capital Fund (WCF) to satisfy specific recurring needs for goods and services through use of a business-like buyer and seller approach under which NASA's WCF entities provide goods or services pursuant to contracts and agreements with their customers. The overarching aim of WCF is to promote economy, efficiency, and accountability with fully reimbursed rates and by focusing on streamlining operations, measuring performance, and improving customer satisfaction.

IT MODERNIZATION

NASA's Office of the Chief Information Officer (OCIO) is in the process of transforming Information Technology (IT) services within the Agency as part of a larger NASA initiative to improve the delivery and efficiency of mission support services. This transformation includes the move from a varied service delivery model, currently customized to each NASA Center, to an Enterprise service delivery model common across all of NASA. A priority NASA objective for this transition to an Enterprise model is to execute IT Modernization consistent with the objectives of the Modernizing Government Technology (MGT) Act (P.L. 115-91, Title X, Subtitle G), within the NASA Working Capital Fund (WCF). Seizing on the unique opportunity afforded by the passage of the MGT Act, NASA proposes in the FY 2023 budget request to amend the existing NASA WCF authority in 51 U.S.C. § 30102 to make the WCF available for IT Modernization activities as set forth in the MGT Act, without reimbursement, and to transfer amounts into the WCF to fund such activities. Adding IT Modernization to the authorized purposes of the NASA WCF, without reimbursement, would permit NASA OCIO to develop a funding model that better supports long-term planning and success for technology modernization and transformation initiatives.

NASA's WCF is comprised of four entities:

- NASA Shared Services Center (NSSC);
- Solutions for Enterprise-Wide Procurement (SEWP) Government-Wide Acquisition Contract;
- Information Technology (IT) Infrastructure Integration Program (I3P); and
- National Center for Critical Information Processing and Storage (NCCIPS).

WORKING CAPITAL FUND

WORKING CAPITAL FUNDS BUDGET SUMMARY

Spending Authority from Offsetting Collections ($ in millions)	Actual FY 2021	Estimate FY 2022	Request FY 2023
NSSC	86	79	81
SEWP	31	42	45
I3P	369	368	230
NCCIPS	39	28	28
Total New Spending Authority	**525**	**517**	**384**
Unobligated Brought Forward, Oct. 1	27	55	56
Recoveries of Prior Yr. Unpaid Obligations	3	6	6
Total Budgetary Resources	**555**	**578**	**446**
NSSC	85	78	81
SEWP	19	35	40
I3P	369	368	230
NCCIPS	27	41	28
Total Obligations	**500**	**522**	**379**
Unobligated Balance (end-of-year) *	**55**	**56**	**67**

**Unobligated balance end-of-year is budgetary resources less obligations*

NASA SHARED SERVICES CENTER (NSSC)

NSSC opened in March 2006 to provide centralized administrative processing services and customer contact center operations for support of human resources, procurement, financial management, Agency IT, and Agency business support services. NASA established NSSC, a function under the NASA Headquarters Mission Support Directorate, as a public/private partnership. NSSC has awarded its major business management and IT services contract to CSRA (Computer Sciences Corporation merged with SRA International). Typical expenditures are related to the civil service workforce, support contractor, other direct procurements, and Agency training purchases.

NSSC is located on the grounds of Stennis Space Center (SSC) and operates in a manner that provides for transparency and accountability of costs and services. NASA has reduced its administrative costs through centralized processing at NSSC. The work performed by NSSC reduces duplicative efforts and increases cost efficiencies.

NSSC's revenue streams include funding from the NASA Mission Support Enterprise Offices, Mission Directorates, and various NASA mission support offices. During FY 2022, NSSC will continue to offer similar services as in FY 2021. During FY 2023, NSSC will continue to offer similar services as in FY 2022 making minor expansions to existing services.

SOLUTIONS FOR ENTERPRISE-WIDE PROCUREMENT (SEWP)

SEWP refers to operations related to the Government-Wide Acquisition Contract that was established under the authority of section 5112 of the Information Technology Management Reform Act (40 U.S.C. 1412(e)), enacted in 1996, under which NASA is designated by the Office of Management and Budget (OMB) as a Federal Government Executive Agent for SEWP contracts.

SEWP was established as a WCF entity to allow all Federal agencies use of a best value tool to purchase IT product solutions and services. Under this approach, the buying power of Federal Agencies is combined to acquire best value for IT products and services more efficiently. Typical acquisitions include a wide range of advanced technologies, such as: UNIX-Linux and Windows-based desktops and servers, peripherals, network equipment, storage devices, security tools, software, and other IT products and product-based solutions.

SEWP promotes aggressive pricing using online tools to obtain multiple, competitive quotes from vendors. On average for FY 2021, SEWP quotes have a 20 percent savings for any Federal customer using SEWP contracts. In addition, SEWP offers a low surcharge to recover NASA's costs to operate the program with an average 0.34 percent fee as compared to the Government standard of 0.75 percent. SEWP revenue is generated solely from the surcharge fees on all transactions processed. For FY 2021, the Federal Government saved about $4.2 billion in fees, based on the difference between General Services Administration (GSA) and SEWP surcharge fees.

IT INFRASTRUCTURE INTEGRATION PROGRAM (I3P)

WCF operations supporting I3P began in early FY 2012. WCF enables I3P to improve the efficiency and economy in which contract services and management are provided to support NASA's IT strategic initiatives and to increase visibility into NASA's IT budget and expenditures. Under I3P, NASA has consolidated 19 separately managed contracts into five centrally managed ones described as follows:

- The Enterprise Applications Service Technologies (EAST2) contract supports Agency Applications Office (AAO) applications hosted by Marshall Space Flight Center (MSFC). The AAO operates and maintains a broad spectrum of NASA's enterprise applications, with an emphasis on fully integrating business process expertise with application and technical knowledge. A small team of civil servants and support contractors sustain operations, implement new applications and capabilities, and provide business readiness support to the stakeholders and end-users.
- The NASA Integrated Communications Services contract (NICS) provides wide and local area network, telecommunications, video, and data services hosted at MSFC. The NICS Contract will be coming to an end and the work will transition to the follow-on contract Advanced Enterprise Global Information Technology (IT) Solutions (AEGIS) on May 1, 2022.
- The Enterprise Applications Service Technologies Web Enterprise Service Technologies (EAST2-WSO) contract provides public website hosting, web content management and integration, and search services. Goddard Space Flight Center (GSFC) and Ames Research Center (ARC) host these services.
- The End User Services Contract (NEST/EUSO) provides program management, provisioning, and support of desktops, laptops, cell phones, personal digital assistants, office automation software, and video conferencing. NSSC hosts these services.

- The Networx Telecommunications Circuits contract provides telecommunication services, which includes tele-conferencing services, core circuit services, mission network services, and regional circuit services hosted at MSFC. The work under the Networx contract slowly started transitioning to the follow-on contract, Enterprise Infrastructure Solutions Contract (EIS) in July 2019 with some services transitioning to the NICS Contract. The transition of work is still ongoing in FY 2022 and should be completely transitioned by the end of FY 2022.

I3P's consolidated contracting approach benefits NASA by providing cost saving opportunities, such as the reduction in administrative burden involved with the business management of contracts and a significant reduction in procurement request transaction volume. Other I3P benefits include: streamlining the budgeting, funding, and costing of I3P services; achieving transparency through the provision of detailed customer monthly billings; and providing consolidated, consistent reporting of Agency-wide consumption of I3P-related goods and services.

I3P is unique in that revenue streams and expenditures are limited to contract costs for its five service contracts. Revenue streams include funding from the NASA centers, NASA mission directorates, and various NASA mission support offices. As reflected in the FY 2022 anticipated funding level, the I3P WCF will continue to offer similar services as in FY 2021. During FY 2023 NSSC will continue to offer similar services as in FY 2022 with one significant change. The follow-on contract for NICS, the Advanced Enterprise Global Information Technology (IT) Solutions (AEGIS) contract will be managed outside of the working capital fund as reflected in the FY 2023 anticipated funding level.

NATIONAL CENTER FOR CRITICAL INFO. PROCESSING AND STORAGE (NCCIPS)

NCCIPS is a Federal shared services data center designed for sensitive and secure processing and storage. NCCIPS is a 211,000 sq. ft. secure data center facility on a 64-acre campus within SSC. NCCIPS offers Federal customers collocation services from a state-of-the-art data center facility. NCCIPS offers 24x7x365 availability at a Tier III level as defined by the Uptime Institute, with complete redundancy in the cooling system and in the electrical distribution system from the national power grid to the rack-level.

NCCIPS provides the following infrastructure/services:

- Five Layer Security – Buffer Zone/perimeter fencing, armed security at all gates, roving guards, and NCCIPS armed guards, and NCCIPS Access Control System;
- Three separate commercial power generation systems available to NCCIPS;
- Tier III redundant (N + 1) power from commercial power systems down to racks on the datacenter floors with N + 1 diesel generator backup;
- Tier III redundant (N + 1) cooling;
- Expert IT staff with a proven track record of uninterrupted service;
- 24x7 facility operations staff monitoring;
- Robust network infrastructure with multiple, discreet communication paths; and
- FE-25 clean agent fire suppression.

The NASA WCF provides NASA with a mechanism to collect amounts sufficient to finance continuing operations, acquire capital assets, and adjust for prior year results of operations, in addition to normal operating expense recovery at NCCIPS. NCCIPS WCF benefits NASA and its customers by:

- Enabling funds to be collected over time and (once earned) used for new equipment and technology;
- Allowing the NSSC to incorporate a level of equipment replacement, maintenance, and technology refresh costs into customer rates;
- Helping to normalize rates charged to NCCIPS customers from year-to-year, as the need for facility repairs, infrastructure upgrades, and routine equipment maintenance increases, thus enabling NCCIPS customers to maintain their appropriation funding without incurring potentially large unplanned expenses;
- Facilitating NCCIPS business opportunities for new customers; and
- Reducing the probability of hardware failure within the NCCIPS operational environment.

The NCCIPS revenue streams include funding from the NASA SSC and NSSC Centers, NASA HQ Office of the Chief Human Capital Officer, and external Federal Agencies, including Department of Homeland Security (DHS), U.S. Army Program Executive Office - Missiles and Space (ARMY – PEO), U.S. Navy Department of Defense Supercomputing Resource Center (DSRC), DOD High Performance Computing Modernization Program – Engineer Research and Development Center (ERDC), National Reconnaissance Office (NRO), Government Services Administration (GSA), Department of Transportation OCIO (DOT-OCIO), DOT Maritime Administration, and Department of Housing and Urban Development (HUD). During FY 2022 and FY 2023, NCCIPS will continue to offer similar services as in FY 2021 with no significant scope changes anticipated.

BUDGET BY OBJECT CLASS

FY 2023 Estimated Direct Discretionary Obligations

($ millions)

Code	Object Class	Deep Space Exploration Systems	Space Operations	Space Technology	Science	Aeronautics	STEM Engagement	Safety, Security, and Mission Services	Construction & Environmental Compliance & Restoration	Office of Inspector General	NASA Total
11.1	Full-time permanent	355	326	125	367	202	7	999	-	26	**2,407**
11.3	Other than full-time permanent	5	3	4	9	7	-	23	-	1	**52**
11.5	Other personnel compensation	3	2	-	1	-	-	60	-	1	**67**
11.8	Special Personal Services Payments	1	-	-	-	-	-	-	-	-	**1**
11.9	*Subtotal Personnel Compensation*	*364*	*331*	*129*	*377*	*209*	*7*	*1,082*	-	*28*	*2,527*
12.1	Civilian personnel benefits	128	116	46	132	74	3	361	-	11	**871**
13.0	Benefits to former personnel	-	-	-	-	-	-	1	-	-	**1**
	Total Personnel Compensation & Benefits	**492**	**447**	**175**	**509**	**283**	**10**	**1,444**	**-**	**39**	**3,399**
21.0	Travel & transport. of persons	13	16	19	21	8	1	13	-	1	**92**
22.0	Transportation of things	-	1,670	6	18	-	-	1	-	-	**1,695**
23.1	Rental payments to GSA	-	-	-	-	-	-	37	-	-	**37**
23.2	Rental payments to others	-	1	1	8	-	-	1	-	-	**11**
23.3	Communications, utilities & misc.	15	10	-	10	7	-	82	2	-	**126**
24.0	Printing & reproduction	-	-	-	1	-	-	2	-	-	**3**
25.1	Advisory & assistance services	447	125	69	161	16	1	415	21	-	**1,255**
25.2	Other services from non-Federal sources	40	173	39	237	33	5	196	66	5	**794**
25.3	Other purchases of goods & services from Government accounts	26	53	56	293	8	-	53	16	-	**505**
25.4	Operation & maintenance. of facilities	136	34	5	12	60	-	249	75	-	**571**
25.5	Research & development contracts	5,594	1,458	940	5,471	419	9	181	11	-	**14,083**
25.6	Medical care	-	-	-	-	-	-	8	-	-	**8**
25.7	Operation & maintenance of equipment	98	214	11	74	43	6	299	3	-	**748**
26.0	Supplies & materials	36	14	10	33	10	-	15	-	-	**118**
31.0	Equipment	420	20	12	135	29	3	163	1	3	**786**
32.0	Land & structures	109	8	-	5	6	-	31	229	-	**388**
41.0	Grants, subsidies, & contributions	52	23	95	1,000	50	115	19	-	-	**1,354**
42.0	Insurance claims and indemnities	-	-	-	-	-	-	-	-	-	-
	Other Object Classes	**6,986**	**3,819**	**1,263**	**7,479**	**689**	**140**	**1,765**	**424**	**9**	**22,574**
	NASA Total, Direct	**7,478**	**4,266**	**1,438**	**7,988**	**972**	**150**	**3,209**	**424**	**48**	**25,973**

Totals may not add due to rounding.

NOTE: The table only reflects the FY 2023 request and does not include remaining funding from previous direct or supplemental appropriations.

STATUS OF UNOBLIGATED FUNDS

The table below displays actual and estimated unobligated balances of direct and reimbursable budget authority in each NASA account at the end of each fiscal year.

END OF YEAR UNOBLIGATED FUNDS SUMMARY BY APPROPRIATIONS ACCOUNT

Budget Authority ($ millions)	Unobligated Balances Sept. 30, 2021	Estimated Unobligated Balances Sept. 30, 2022	Estimated Unobligated Balances Sept. 30, 2023
Deep Space Exploration Systems	161	294	427
Space Technology	27	43	73
Space Operations	290	494	698
Science	875	932	989
Aeronautics	20	32	44
STEM Engagement	8	10	12
Safety, Security, and Mission Services	763	891	939
Construction and Environmental Compliance and Restoration	335	412	499
Working Capital Fund	55	56	67
Science, Space, and Technology Education Trust Fund	1	1	1
Total NASA	**2,535**	**3,165**	**3,749**

Totals may not add due to rounding.

REIMBURSABLE ESTIMATES

Reimbursable agreements are agreements where the NASA costs associated with the undertaking are borne by the non-NASA partner. NASA undertakes reimbursable agreements when it has equipment, facilities, and services that it can make available to others in a manner that does not interfere with NASA mission requirements. Reimbursable agreements are executed under various legal authorities including:

- National Aeronautics and Space Act of 1958, as amended [P.L. 85–568] - Space Act Agreements (SAAs) and Enhanced Use Leasing (EUL) authority [incorporated through P.L. 108-7].
- Commercial Space Launch Act [P.L. 98-575] – authority to outsource the use of its launching facilities and services to private companies.
- National Historic Preservation Act (NHPA) [P.L. 89-665] – leasing authority for historic property.
- Government Employees Training Act [P. L. 85-507] – authority to conduct employee training for other government organizations.
- Economy Act [P.L. 31–15359] – authority for agencies to obtain supplies or services from another agency.

The agreements are transacted in three accounts (SSMS, CECR, and OIG). Most of the work is managed by a specific NASA center and performed by the relevant mission directorate or office program at the center (i.e., Aeronautics, Human Exploration and Operations, Exploration Technology, Mission Support, Office of STEM Engagement, and Office of Inspector General). Examples include the use of NASA-operated wind tunnel test facilities and rocket test stand facilities by other Government agencies or private sector users. Some larger agreements and those that involve multiple centers or mission directorates are managed by NASA Headquarters. For example, NASA serves as the acquisition agent for the *GOES* series of satellites operated by the National Oceanographic and Atmospheric Administration.

The table below presents the budget authority for NASA's reimbursable work. As most reimbursable requests to NASA do not occur until the year of execution, the FY 2022 and FY 2023 estimates are based on anticipated reimbursable agreements reported by NASA centers and Headquarters units.

REIMBURSABLE BUDGET AUTHORITY BY APPROPRIATIONS ACCOUNT

($ millions)	Actual FY 2021	Estimate FY 2022	Estimate FY 2023
Safety, Security, and Mission Services (including EUL and NHPA)	1,463	1,671	1,458
Construction and Environmental Compliance and Restoration (including EUL)	21	30	30
Office of Inspector General	1	2	2
Total	**1,485**	**2,160**	**1,853**

ENHANCED USE LEASING

In 2003, Congress authorized NASA to enter into leasing arrangements at two centers. In 2007 and 2008, Congress expanded that authority such that NASA may enter into Enhanced Use Leasing (EUL) arrangements at all centers. EUL revenues help NASA maintain critical facilities and address deferred maintenance challenges as well as support centers' revitalization plans. Additionally, NASA's EUL authority supports important relationships with industry, academia, and non-profit organizations.

NASA's EUL authority expired without an extension on December 31, 2021, pursuant to the "sunset" provision in 51 U.S.C. 20145(g). However, Title II of Division O of the FY 2022 Omnibus Appropriations Act extends the existing EUL authority through December 31, 2022.

After deducting the costs of administering the leases, centers are permitted to retain 65 percent of net receipt revenue. The balances are made available to NASA for use Agency-wide. These funds are in addition to annual appropriations. The table below depicts the estimated FY 2023 EUL expenses and revenues. The amounts identified under Capital Asset Account Expenditures may be adjusted between projects listed based on actual contract award. There are no civil servants funded from EUL income.

SUMMARY OF PROJECTED FY 2023 EUL ACTIVITY

FY2023 EUL Expenses and Revenues ($ Thousands)	ARC	GRC	GSFC	JPL (NMO)	MSFC	SSC	KSC	Agency	Total
Base Rent	10,670.6	50.6	59.1	106.1	2,448.0	375.0	2,908.7	3,000.0	19,618.2
Institutional Support Income	729.1		8.5		1,003.0	44.6	305.0		2,090.2
Additional Reimbursable Demand Services Requested by Lessees (including overhead)	6,403.7					18.0	133.6	749.0	7,304.3
Total Lease Income - Program Year 2023	**17,803.4**	**50.6**	**67.6**	**106.1**	**3,451.0**	**437.6**	**3,347.3**	**3,749.0**	**29,012.7**
Institutional Support Costs	-729.1		-8.5		-85.0	-42.9	-305.0	0.0	-1,170.5
Lease Management and Administration	-1,790.0	-6.3		21.2	-2,448.0	-1.7		0.0	-4,224.8
Tenant Building Maintenance and Repair	-350.0	-10.9						-2,000.0	-2,360.9
Cost to Fulfill Reimbursable Demand Services (including overhead)	-6,403.7	0.0	0.0	0.0	0.0	-18.0	-133.6	-749.0	-7,304.3
Total Cost Associated with Leases (N Fund) - Program Year 2023	**-9,272.8**	**-17.2**	**-8.5**	**21.2**	**-2,533.0**	**-62.6**	**-438.6**	**-2,749.0**	**-15,060.5**
Net Revenue from Lease Activity (E Fund) - Program Year 2023	**8,530.6**	**33.4**	**59.1**	**127.3**	**918.0**	**375.0**	**2,908.7**	**1,000.0**	**13,952.1**
Projected Balance, Capital Asset Account - Prior Program Years	687.8	203.5	51.4	271.3	487.4	393.5	1,329.0	7,248.4	10,672.2
Net Revenue from Lease Activity Retained at Center - Program Year 2023	5,544.9	21.7	38.4	82.7	596.7	243.8	1,890.6	5,607.5	14,026.3
Total Available, Capital Assest Account - All Program Years	**6,232.7**	**225.2**	**89.8**	**354.0**	**1,084.1**	**637.3**	**3,219.6**	**12,856.0**	**24,698.6**
Planned Maintenance, Various Buildings	-5,713.3		-85.0				-2,000.0		-7,798.3
Energy and Sustainability Upgrades, Various Buildings (Stennis)						-150.0			-150.0
Energy and Sustainability Upgrades, Various Buildings (Various Centers)								-6,934.6	-6,934.6
Capital Asset Account Expenditures	**-5,713.3**	**0.0**	**-85.0**	**0.0**	**0.0**	**-150.0**	**-2,000.0**	**-6,934.6**	**-14,882.9**
Capital Asset Account Ending Balance	**519.4**	**225.2**	**4.8**	**354.0**	**1,084.1**	**487.3**	**1,219.6**	**5,921.4**	**9,815.7**
In Kind Activity	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**41.1**	**0.0**	**41.1**

ENHANCED USE LEASING

DEFINITIONS

Base Rent

Revenue collected from the tenant for rent of land or buildings lease.

Institutional Support Costs

Cost for institutional shared services, such as fire, security, first responder, communications, common grounds, road, and infrastructure maintenance, as well as routine administrative support and management oversight (e.g., environmental).

Total Lease Income

Total gross proceeds from EUL activities including expenses due to renting NASA property.

In-Kind Activity

Consideration accepted in lieu of rent payment (only applies to selected leases signed prior to January 1, 2009).

Reimbursable Demand Services

Services such as janitorial, communications, and maintenance that solely benefit the tenant and are provided for their convenience. There is no net income received by NASA, as these payments may only cover the costs of NASA and its vendors providing these services.

NATIONAL HISTORIC PRESERVATION ACT

The National Historic Preservation Act (NHPA) 54 U.S.C. §306121-306122 provides that:

[(a) Notwithstanding any other provision of law, any Federal agency after consultation with the Council [the Advisory Council on Historic Preservation], shall, to the extent practicable, establish and implement alternatives for historic properties, including adaptive use, that are not needed for current or projected agency purposes, and may lease an historic property owned by the agency to any person or organization, or exchange any property owned by the agency with comparable historic property, if the agency head determines that the lease or exchange will adequately insure the preservation of the historic property.

(b) The proceeds of any lease under subsection (a) may, notwithstanding any other provision of law, be retained by the agency entering into such lease and used to defray the costs of administration, maintenance, repair, and related expenses incurred by the agency with respect to such property or other properties which are on the National Register which are owned by, or are under the jurisdiction or control of, such agency. Any surplus proceeds from such leases shall be deposited into the Treasury of the United States at the end of the second fiscal year following the fiscal year in which such proceeds were received.

(c) The head of any Federal agency having responsibility for the management of any historic property may, after consultation with the Advisory Council on Historic Preservation, enter into contracts for the management of such property. Any such contract shall contain such terms and conditions as the head of such agency deems necessary or appropriate to protect the interests of the United States and insure adequate preservation of historic property.]

In FY 2014, NASA established a program for leasing its historic properties based upon the NHPA authorities. Funds received from historic property leases are expended for the purposes of operating, maintaining, and managing the properties, or for authorized demolition or removal of buildings. Federal workforce costs associated with executing the leasing program are funded from annual appropriations not leasing revenues.

NATIONAL HISTORIC PRESERVATION ACT

The table below depicts the estimated amounts of anticipated NHPA expenses and revenues for FY 2023. NASA currently expects total rental income of approximately $24.2 million. Of the $24.3 million in total rental income, approximately $6.3 million represents net revenue from lease activities. The net revenue amount of $6.3 million will be used for historic building maintenance and repairs at Ames Research Center (ARC).

FY2023 NHPA Expenses and Revenues ($ thousands)	Ames Research Center
Base Rent	15,500.0
Security Deposit (Reissue)	-
Institutional Support Income	
Cost to Fuflill Reimbursable Demand Services	8,753.5
Total Rental Income (N Fund and E Fund Lease Project Code)	**24,253.5**
Institutional Support Costs	(8,798.7)
Security Deposit (Reissue)	-
Lease Management and Administration	(451.0)
Reimbursable Demand Services Requested by Leasees	(8,753.5)
Total Cost Associated with Leases (N Fund)	**(18,003.2)**
Net Revenue from Lease Activity (E Fund Lease Project Code)	**6,250.3**
Unobligated Proceeds Prior Years (as of 9/30/2023)	**-**
Deferred Maintenance for Buildings 2, 10, 15, 16, 17, 19, 20, 25, 26, N200, N226, N227, N234, N238 & N243	(1,765.0)
Section 106 Consultation with SHPO	(75.0)
Renovate Building 20, Phase 3 of 4	(4,410.3)
Capital Asset Account Expenditures (E Fund)	**(6,250.3)**
Capital Asset Account Ending Balance (E Fund)	**-**
In Kind Activity	**-**

NATIONAL HISTORIC PRESERVATION ACT

DEFINITIONS

Base Rent

Revenue collected from the tenant for rent of land or buildings.

In-Kind

Consideration accepted in lieu of rent payment.

Institutional Support Costs

Cost for institutional shared services such as fire, security, first responder, communications, common grounds, road, and infrastructure maintenance, as well as routine administrative support and management oversight (e.g., environmental).

Reimbursable Demand Services

Services such as janitorial, communications, and maintenance that solely benefit the tenant and are provided for their convenience. There is no net income received by NASA, as these payments may only cover the costs of NASA and its vendors providing these services.

Total Rental Income

Total gross proceeds from NHPA activities including expenses due to renting NASA property.

BUDGET FOR SAFETY OVERSIGHT

The following table provides the safety oversight budget request. This includes the Agency-wide surveillance functions as well as the project specific safety, reliability, maintainability, and quality assurance elements embedded within individual projects. NASA does not have a single safety oversight budget line item, but instead amounts are embedded in program, project, and mission support budgets.

BUDGET SUMMARY FOR SAFETY OVERSIGHT

	Actual	Estimate	Request				
Budget Authority ($ millions)	FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Safety and Mission Assurance	47.9	51.0	52.6	53.6	54.7	55.8	56.9
Institutional Safety	37.7	37.4	37.4	38.1	38.9	39.7	40.5
SMA Technical Authority	53.8	53.3	53.3	54.4	55.5	56.6	57.7
Agency-Wide Safety Oversight	**$139.4**	**$141.8**	**$143.3**	**$146.1**	**$149.1**	**$152.0**	**$155.1**
Program Specific*	**$300.0**	**$300.0**	**$300.0**	**$300.0**	**$300.0**	**$300.0**	**$300.0**
NASA Total, Safety**	**$439.4**	**$441.8**	**$443.3**	**$446.1**	**$449.1**	**$452.0**	**$455.1**

** Estimated values*

***Totals may not add due to rounding*

Agency-Wide Safety Oversight – Agency-level programs and activities that support the overarching NASA Safety and Mission Success program.

Safety and Mission Assurance – The Safety and Mission Assurance (S&MA) program administers and refines the pertinent policies, procedural requirements, and technical safety standards. The program participates in forums that provide advice to the Administrator, Mission Directorates, Program Managers, and Center Directors who are ultimately accountable for the safety and mission success of all NASA programs, projects, and operations. The program's policy focuses on protecting the public, workforce, high-value property, and the terrestrial, orbital, and planetary environments from potential harm; assuring crew safety and mission success; and cultivating a robust Safety Culture that values and pursues technical and organizational excellence to understand and reduce risk. Notable S&MA managed programs include but are not limited to, NASA's Orbital Debris program (measurements and modeling of orbital debris; characterizing the debris environment; mitigation standards development and review), the NASA Safety Center's S&MA Technical Excellence Program and NASA's Electronic Parts Program. The budget for the Safety and Mission Assurance is part of the Agency Technical Authority (ATA) program under the Safety, Security, and Mission Services (SSMS) mission account.

Institutional Safety – NASA's Institutional Safety program is driven by 29 CFR 1960, Basic Program Elements for Federal Employee Occupational Safety and Health Programs and Related Matters, NASA Procedural Requirement (NPR) 8715.1A, NASA Occupational Safety and Health Programs, and NPR 7900.3, Aircraft Operations Management Manual. The program includes: risk management, safety training, safety awareness, construction safety, the voluntary protection program, safety metrics and trend analysis, contractor insight/oversight, support to safety boards and committees, support to the emergency preparedness and fire safety programs, aviation safety, explosives and propellants safety, nuclear safety, radiation safety, confined space entry, fall protection, lifting devices, pressure vessel safety, hazard reporting and abatement systems, cryogenic safety, electrical safety requirements (lock out/tag out), facility systems safety, institutional safety policy development, visitor and public safety, institutional safety engineering, and a mishap prevention program including a reporting system and investigations. The Institutional Safety program requires significant Federal, State, and local coordination. The budget for Institutional Safety is part of the Center Engineering, Safety, and Operations (CESO) program under the SSMS mission account.

S&MA Technical Authority – S&MA Technical Authority provides independent oversight of programs and projects in support of safety and mission success and is a key part of NASA's overall system of checks and balances. The S&MA Technical Authority program includes travel and labor only for all S&MA supervisors, branch chiefs or above and designated deputies. In addition, where the principal job function of a non-supervisory S&MA person consists of rendering authoritative decisions on S&MA matters relating to the design or operation of a program or project, that person's salary is included. Often, these positions are the lead S&MA managers for large programs where the decision-making process is nearly a full-time demand. This category does not include salaries for individuals who only occasionally work on an authority task; however, the program budget does include travel funds in direct support of these tasks when needed. The budget for S&MA Technical Authority is part of the CESO program under the SSMS mission account.

Program Specific – Program specific S&MA costs are included in individual project budgets and are reflected in the table above using a rough order of magnitude estimate. These costs include the technical and management efforts of directing and controlling the safety and mission assurance elements of the project. This incorporates the design, development, review, and verification of practices and procedures and mission success criteria intended to assure that the delivered spacecraft, ground system, mission operation, or payload meets performance requirements and function for their intended lifetimes.

PHYSICIANS' COMPARABILITY ALLOWANCE

Department and component:

National Aeronautics and Space Administration (NASA)

Purpose: The purpose of this document is to describe the Agency's plan for implementing the Physicians' Comparability Allowance (PCA) program. Per 5 CFR 595.107, the Office of Management and Budget (OMB) must approve this plan prior to the Agency entering into any PCA service agreement. Changes to this plan must be reviewed and approved by OMB in accordance with 5 CFR 595.107.

Reporting: In addition to the plan, each year, components utilizing PCA will include their PCA worksheet in the OMB Justification (OMBJ), typically in September. OMB and the Office of Personnel Management (OPM) will use this data for budget development and congressional reporting.

Plan for Implementing the PCA program:

1) Identify the categories of physician positions the agency has established are covered by PCA under § 595.103. Please include the basis for each category. If applicable, list and explain the necessity of any additional physician categories designated by your agency (for categories other than I through IV-B). List Any Additional Physician Categories Designated by Your agency: Pursuant to 5 CFR 595.107, any additional category of physician receiving a PCA, not covered by categories I through IV-B, should be listed and accompanied by an explanation as to why these categories are necessary.

Number of Physicians Receiving PCAs by Category (non-add)	**Category of Physician Position**	**Covered by Agency** (mark "x" if covered)	**Basis for Category**
18	Category I Clinical Position	x	Difficulty recruiting and retaining: Physicians in this category perform both operational medical support that is mission-critical and provide medical subject matter expertise in the development and operation of current and future programs, including, but not limited to the International Space Station, Artemis, Gateway, and the Human Lander System. Much of the work they do is inherently governmental, as it requires establishing requirements, both for spaceflight programs and for commercial offers in NASA procurements for spaceflight capabilities. These specialized physicians are often called on to evaluate commercial and international partner proposals for medical capabilities. These physicians also provide leadership in NASA's multilateral medical operations, representing NASA in multilateral fora. Civil Servant physicians are also required to provide oversight of key contract functions that support mission-critical activities.
0	Category II Research	N/A	N/A

PHYSICIANS' COMPARABILITY ALLOWANCE

Number of Physicians Receiving PCAs by Category (non-add)	Category of Physician Position	Covered by Agency (mark “x” if covered)	Basis for Category
	Position		
0	Category III Occupational Health	N/A	N/A
0	Category IV-A Disability Evaluation	N/A	N/A
13	Category IV-B Health and Medical Admin.	x	Difficulty recruiting and retaining: Management physicians play a critical role in ensuring NASA’s ability to meet its’ ambitious goals of returning humans to the Moon in 2024, expanding commercial access to space, and eventually sending humans out into the solar system. These physicians occupy positions that are primarily comprised of inherently governmental activities, including: supervision of other civil servant physicians; oversight of significant projects and programs, such as the Johnson Space Center (JSC) Clinic; providing independent oversight of NASA’s health and medical activities through the Health and Medical Technical Authority; developing and assessing the risk associated with NASA standards that are applicable to all human spaceflight programs and NASA’s commercialization activities; and serving as Chief Medical Officer at the Agency, Center, and Program levels to make ultimate determinations that affect Agency action and resources.

2) Explain the recruitment and retention problem(s) for each category of physician in your agency (this should demonstrate that a current need continues to persist). § 595 of 5CFR Ch. 1 requires that an agency may determine that a significant recruitment and retention problem exists only if all of the following conditions apply:
- Evidence indicates that the agency is unable to recruit and retain physicians for the category;
- The qualification requirements being sought do not exceed the qualifications necessary for successful performance of the work;
- The agency has made efforts to recruit and retain candidates in the category; and
- There are not a sufficient number of qualified candidates available if no comparability allowance is paid.

PHYSICIANS' COMPARABILITY ALLOWANCE

Number of Physicians Receiving PCAs by Category (non-add)	Category of Physician Position	Recruitment and retention problem
18	Category I Clinical Position	NASA physicians who receive PCA are located at JSC in Houston, Texas; Kennedy Space Center in Cape Canaveral Fl, Goddard Space Flight Center in Greenbelt, Maryland; and Headquarters in Washington D.C. Physician salaries in the Houston area and across the country continue to rise and the General Schedule (GS) salaries that JSC may offer are consistently lower than private sector salaries and those offered by our prime contractors. According to the 2021 Medscape Physician Compensation Report, the average physician compensation in the South-Central geographical area was $320,000. In 2022, the maximum GS salary payable for GS employees is $176,300. In addition, significantly higher physician pay scales under Title 38 in the Veterans Administration (VA) and Department of Defense (DoD) provide a potential incentive for NASA physicians to continue their Government service and receive higher pay by transferring to those agencies. Although NASA has recently been granted initial approval to pursue Title38 pay by OMB, the implementation of this authority has not yet been established. Furthermore, NASA is currently competing with commercial spaceflight companies, including SpaceX, Virgin Galactic and Axiom Space that are rapidly expanding human spaceflight capabilities and require physicians experienced in aerospace medicine and human spaceflight operations. NASA physicians are supporting more critical program activities simultaneously than at any time in the past. This includes supporting the NASA Health and Medical Technical Authority, International Space Station crew (operating 24/7), Commercial Crew, Orion, Gateway, and Lunar activities; the active astronaut corps; and the operation of the Lifetime Surveillance of Astronaut Health program, which includes all retired astronauts. NASA physicians are supporting more critical program activities simultaneously than at any time in its history. This includes supporting the NASA Health and Medical Technical Authority, International Space Station crew (operating 24/7), Commercial Crew Program, Artemis Program (Orion MPCV, Gateway, and Human Landing System); Commercial Low Earth Orbit Program; the active Astronaut Corps including the newly selected Astronaut Candidate Class of 2022; and the Lifetime Surveillance of Astronaut Health program, which includes all management and former astronauts. The implementation of the TREAT Astronauts Act entails the provision of life-long care for former astronauts who have developed medical ailments related to their spaceflight careers, further requiring physicians who are

Number of Physicians Receiving PCAs by Category (non-add)	Category of Physician Position	Recruitment and retention problem
		able to address the unique medical and behavioral health needs of former astronauts. Physicians who are board-certified in Aerospace Medicine as well as a primary medical specialty and who possess operational spaceflight operations experience are a rare and valuable commodity. There is an acute shortage of experienced aerospace medicine specialists nationwide and other Government and military organizations are actively recruiting qualified physicians with such skills. Many of the JSC physicians with aerospace medicine training and experience are also board-certified in other clinical specialties including internal medicine, emergency medicine, family medicine, occupational medicine, and psychiatry. These double board-certified physicians are an especially rare commodity, and their dual areas of expertise are extraordinarily valuable to NASA. The training period after medical school, including on-the-job training at NASA after hire, is nearly a full decade in duration. Recruitment of such uniquely qualified physicians is becoming more difficult. A recent vacancy at the Johnson Space Center for an aerospace medicine physician required nearly two years to successful fill. Retaining such physicians, after they are hired and have completed NASA Flight Surgeon training requirements, is critical to the success of the human space flight program. All of these factors affect NASA's ability to attract, recruit and retain qualified physicians to support the human spaceflight program. Without offering PCA, NASA would not be able to recruit and retain such highly qualified physicians.
0	Category II Research Position	N/A
0	Category III Occupational Health	N/A
0	Category IV-A Disability Evaluation	N/A
13	Category IV-B Health and Medical Admin.	In addition to the challenges listed in Category I, NASA faces challenges recruiting and retaining physicians who are willing and able to serve in physician management and leadership roles. Because physicians are at the top of the GS pay scale, and previously, NASA had only one PCA category, there has

PHYSICIANS' COMPARABILITY ALLOWANCE

Number of Physicians Receiving PCAs by Category (non-add)	Category of Physician Position	Recruitment and retention problem
		been no pay incentive to accompany the increase in responsibility and authority. In 2019-2021, NASA placed eight physicians who occupy significant medical management and leadership positions into a separate PCA category that provides the opportunity for $6,000 in additional PCA pay within NASA's PCA pay structure. Physician leaders are in even greater demand than skilled aerospace physicians. Additional PCA for those holding these critical roles helps to attract the best physicians to these roles and retain them in leadership and management positions. Over the past few years, NASA has been unable to fill critical branch and division leadership positions that require physicians, and, as a result, has been unable to develop a robust succession management plan to ensure physician leaders are developed and retained to fill critical Agency roles (e.g., Chief Medical Officer, Chief Health and Medical Officer). Providing enhanced PCA for those physicians willing to step up to roles of increased responsibility will encourage young physicians to apply for these challenging roles and ensure a cadre of skilled physician leaders for the future.

3) Explain how the agency determines the amounts to be used for each category of physicians.

Number of Physicians Receiving PCAs by Category (non-add)	Category of Physician Position	Basis of comparability allowance amount
18	Category I Clinical Position	The PCA amounts paid are the minimum needed to deal with the recruitment and retention problems. The amount $22,000 - $24,000 is offered to many of our physicians in this category (or $14,000 per regulations, depending on tenure), and we have determined that amount is justified via two means: (1) Market Data relevant to the most applicable field of practice, Emergency Medicine, includes the following: - According to a March 2021 publication by Doximity, a reputable source, Single Board-Certified Emergency Medical Physicians in America make an average of $336,000 per year. - According to a September 2021 publication by the Houston Medical Journal, a reputable source, the average salary for an Emergency Medical Physician in the Houston Metropolitan Area makes more than $350,000 per year. Double Board-Certified physicians can easily make more. (2) NASA Centers have had success hiring candidates with the offers of $14,000 - $24,000 of PCA; therefore, a higher amount of PCA would not be justifiable for physicians in this category.
0	Category II Research Position	Currently no physician positions in this category
0	Category III Occupational Health	Currently no physician positions in this category
0	Category IV-A Disability Evaluation	Currently no physician positions in this category
13	Category IV-B Health and Medical Admin.	The PCA amounts paid are the minimum needed to deal with the recruitment and retention problems. Similar research and rationale went into making initial offers for PCA for Physicians in this category; however, we have determined that $14,000 - $24,000 has not been satisfactory in recruiting NASA physicians to take on the additional work burdens of Health and Medical Administration duties and retaining them in such a position. The maximum amount of PCA Allowed by law, $30,000 will be required to satisfy this recruitment and retention effort.

4) Does the agency affirm that the PCA plan is consistent with the provisions of 5 U.S.C. 5948 and the requirements of § 595 of 5 CFR Ch. 1?

Yes

IT STATEMENT OF AFFIRMATION

National Aeronautics and
Space Administration

Headquarters
Washington, DC 20546-0001

Reply to Attn of: **Office of the Chief Information Officer**

TO: NASA Chief Financial Officer, Margaret Schaus

FROM: NASA Chief Information Officer, Jeff Seaton

SUBJECT: Fiscal Year 2023 NASA IT Budget Justification Statement of Affirmation

As required by the Office of Management and Budget (OMB) Circular A-11 and the Federal Information Technology Acquisition Reform Act (FITARA), and based on the information presented from the Offices of the Chief Information Officer, and on insights into the current Information Technology (IT) Portfolio over which the Chief Information Officer (CIO) has direct budget authority, this letter affirms the following:

1. The CIO's common baseline rating for Element D ("CIO reviews and approves major IT Investment portion of budget request") is fully implemented;

2. The Chief Financial Officer (CFO) and the CIO jointly affirm that the CIO had a significant role in reviewing planned IT support for major program objectives;

3. Significant increases and decreases in IT resources are reflected in the Agency's current services baseline budget submission for those items over which the CIO has direct budget authority;

4. The CIO has reviewed and approved the use of incremental development for all investments submitted as major investments in the IT Portfolio;

5. The CIO holds the role of NASA's Senior Agency Official for Privacy (SAOP) and has therefore reviewed the IT Budget submission to ensure that privacy requirements and any associated costs, are explicitly identified and included with respect to any IT resources that will be used to create, collect, use, process, store, maintain, disseminate, disclose, or dispose of personally identifiable information (PII);

6. Agency budget request funding levels will include expected contributions to the E-Gov Line-of-Business initiatives;

7. The CIO collaborated with the Information Technology Council (ITC) comprised of Missions, Centers and Mission Support including the CFO on the IT Budget submission;

IT STATEMENT OF AFFIRMATION

8. The IT Portfolio (OMB Circular A-11, Section 55.6 and as described herein) includes appropriate estimates of all IT resources included in the President's Budget; and

9. The CIO has reviewed and had significant input in approving all IT Investments included in the President's Budget.

Margaret Schaus Digitally signed by Margaret Schaus Date: 2022.03.23 18:16:35 -04'00'

Margaret V. Schaus
Chief Financial Officer

JEFFREY SEATON Digitally signed by JEFFREY SEATON Date: 2022.03.23 16:40:43 -04'00'

Jeffrey M. Seaton
Chief Information Officer

BUDGET FOR PUBLIC RELATIONS

The NASA budget for Communications is funded within the Safety, Security, and Mission Services account under Mission Services & Capabilities, Mission Enabling Services. These program activities include strategic planning and coordination to ensure the consistency of information disseminated to the public through the news media, digital interfaces, and NASA websites. The content supports inherently governmental and external communications; public inquiries; NASA TV; the nasa.gov portal (see: http://www.nasa.gov); Freedom of Information Act requests; history, archival, and artifact management; public affairs/public relations; Center newsletters; guest operations (including bus transportation); and other multimedia support.

NASA COMMUNICATIONS BUDGET SUMMARY, BY CENTER

Budget Authority (in $ millions)	Actual	Estimate	Request				
	FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
ARC	3.0	4.5	4.5	4.6	4.7	4.8	4.9
AFRC	1.7	1.6	1.7	1.8	1.8	1.9	1.9
GRC	4.3	4.8	4.7	4.8	4.9	5.0	5.1
GSFC	6.7	5.8	5.7	5.8	5.9	6.0	6.1
HQ	13.1	20.6	18.9	19.3	19.7	20.1	20.5
JSC	7.6	5.1	5.8	6.0	6.1	6.2	6.3
KSC	8.7	9.2	10.6	10.8	11.1	11.3	11.5
LARC	3.0	3.2	3.1	3.1	3.2	3.2	3.3
MSFC	5.2	5.2	6.6	6.7	6.8	7.0	7.1
SSC	1.6	1.5	1.7	1.7	1.8	1.8	1.8
NASA Total *	**54.9**	**61.6**	**63.3**	**64.6**	**65.9**	**67.2**	**68.5**

The Office of Communications per baseline service level definition as part of the Safety, Security, and Mission Services Budget. Consolidation of enterprise managed services is disbursed to Center locations based on annual requirements.

**Totals may not add due to rounding.*

CONSULTING SERVICES

NASA uses paid experts and consultants to provide advice and expertise beyond that which is available from its in-house civil service workforce. Management controls ensure that there is ample justification for consulting services before these services are obtained. Much of the Agency's expert and consultant support is for the NASA Advisory Council and the Aerospace Safety Advisory Panel. NASA uses experts and consultants to provide expertise on the selection of experiments for future space missions. The use of these experts and consultants provides the Agency with an independent view that promotes the selection of experiments likely to have the greatest scientific merit. Other individuals provide independent views of technical and functional problems to offer senior management a wide range of information to support decision-making. Historically, each mission directorate engages a few consultants to primarily support programmatic and Aerospace Safety Advisory Panel issues.

NASA CONSULTING SERVICES BUDGET SUMMARY

	Actual	Estimate	Request
(Cost in $ millions)	**FY 2021**	**FY 2022**	**FY 2023**
Number of Paid Experts and Consultants	37	37	37
Annual FTE Usage	7.8	7.8	7.8
Salaries	$1.1	$1.1	$1.1
Benefits Costs	$0.1	$0.1	$0.1
Travel Costs	$0.2	$0.2	$0.2
Total Costs	**$1.4**	**$1.4**	**$1.4**

FY 2021 are actual obligations. FY 2022 and FY 2023 are estimated Budget Authority

A broader definition of consulting services could include the total of the Advisory and Assistance Services object class as shown in the Supporting Data - Budget by Object Class section of this volume. Advisory and Assistance Services includes: (1) Quality Control, Testing, and Inspection Services; (2) Management and Professional Support Services; (3) Studies, Analysis, and Evaluations; (4) Engineering and Technical Services; and (5) IT Services.

	Actual	Estimate	Request
(Cost in $ millions)	**FY 2021**	**FY 2022**	**FY 2023**
Quality Control, Testing & Inspection Services	$55.9	$55.3	$61.8
Management and Professional Support Services	$747.0	$738.4	$825.2
Studies, Analysis, & Evaluations	$77.9	$77.0	$86.0
Engineering and Technical Services	$10.1	$10.0	$11.2
IT Services	$245.1	$242.3	$270.8
Total Costs, Advisory & Assistance Services	**$1,136.0**	**$1,123.0**	**$1,255.0**

CONSULTING SERVICES

DEFINITIONS

Consultant - A person who can provide valuable and pertinent advice generally drawn from a high degree of broad administrative, professional, or technical knowledge or experience. When an agency requires public advisory participation, a consultant also may be a person who is affected by a particular program and can provide useful views from personal experience.

Expert - A person who is specially qualified by education and experience to perform difficult and challenging tasks in a particular field beyond the usual range of achievement of competent persons in that field. An expert is regarded by other persons in the field as an authority or practitioner of unusual competence and skill in a professional, scientific, technical, or other activity.

These definitions are located under 5 CFR 304.102. The appointments are made under 5 U.S.C. 3109, and the use of this authority is reported to Office of Personnel Management (OPM).

E-GOV INITIATIVES AND BENEFITS

E-GOVERNMENT FUNDING CONTRIBUTIONS AND SERVICE FEES BY INITIATIVE

NASA will provide funding contributions in FY 2023 for each of the following E-Government initiatives:

Initiative	2023 Contributions (Includes In- Kind) ($ In Dollars)	2023 Service Fees* ($ In Dollars)
E-Rulemaking	-	12,197
Grants.gov	75,000	-
E-Training	-	1,583,625
Recruitment One-Stop	-	129,375
Enterprise HR Integration	-	357,500
E-Payroll	-	3,950,075
E-Travel	-	89,520
Integrated Award Environment (IAE)	-	719,644
Financial Management LoB	124,236	-
Human Resources Management LoB	68,478	-
Geospatial LoB	225,000	-
Budget Formulation and Execution LoB**	120,000	-
Federal PKI Bridge	-	169,792
Hiring Assessment	66,000	-
Unique Entity Identifier Implementation (UEI)	328,572	-
NASA Total	**1,007,286**	**7,011,728**

**Service fees are estimates as provided by the E-Government initiative Managing Partners*

***Final FY 2023 commitments have yet to be finalized by Managing Partners (OMB MAX)*

After submission of the budget, NASA will post FY 2023 Exhibit 300 IT business cases on the IT Dashboard located at: https://www.itdashboard.gov

The E-Government initiatives serve citizens, businesses, and Federal employees by delivering high-quality services more efficiently at a lower price. Instead of expensive "stove-piped" operations, agencies work together to develop common solutions that achieve mission requirements at a reduced cost, which makes resources available for higher priority needs. Benefits realized by NASA through these initiatives in FY 2023 are described below:

e-Rulemaking (Managing Partner EPA) FY 2023 Benefits

NASA has benefited from the e-Rulemaking initiative by being able to better provide the public with one-stop access to the Agency's information on rulemakings and non-rulemaking activities via the Regulations.gov website (see: https://www.regulations.gov/).

NASA uses the Federal Docket Management System (FDMS) to post its rulemakings so that the public can gain access to review and comment on these rulemakings. NASA relies on Regulations.gov to retrieve public comments on its rulemakings. NASA's use of the FDMS and Regulations.gov substantially improves the transparency of its rulemaking actions and increases public participation in the regulatory process. Direct budget cost savings and cost avoidance has resulted from the FDMS and Regulations.gov.

Grants.gov (Managing Partner HHS) FY 2023 Benefits

In addition to the Federal requirement for all grant-issuing agencies to, at a minimum, post a synopsis of all new grant and cooperative agreement funding opportunities to Grants.gov (see: https://www.grants.gov/), the Grants.gov initiative benefits NASA and its grant programs by providing a single location with broader exposure to publish grant and cooperative agreement funding opportunities and application packages. Posting internally, NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES), as well as externally (Grants.gov), makes the process easier for applicants to apply for funding with multiple agencies. All 26 major Federal grant-making agencies post 100 percent of their synopses for discretionary funding opportunity announcements on Grants.gov.

In addition, Grants.gov provides a single site for the grantee community to apply for grants using a standard set of forms, processes, and systems. This gives grantees greater access and ability to apply for Federal funding. Through the continued use of Grants.gov, NASA can reduce operating costs associated with online grant posting and application evaluation. Additionally, the Agency is able to improve operational effectiveness through the use of Grants.gov by increasing data accuracy and reducing processing cycle times.

e-Training (Managing Partner OPM) FY 2023 Benefits

The e-Training initiative provides access to premier electronic training systems and tools that support the training and development of the Federal workforce. The initiative supports Agency missions through efficient one-stop access to e-Training products and services. The availability of an electronic training environment enhances the ability of the Federal Government and NASA to attract, retain, manage, and develop highly skilled professionals needed for a flexible and high-performing Government workforce.

The e-Training initiative benefits NASA by reducing redundancies and achieving economies of scale in the purchase, development, and deployment of e-learning content and in the management of learning technology infrastructure. This initiative also allows NASA to remain in a positive security posture since access to applications are based upon required training being completion and real-time integrations with our identity and credential access management systems. The System for Administration, Training, and Educational Resources at NASA (SATERN) is a web-based talent management tool that serves as NASA's training system of record for over 100,000 active civil servants and contractor accounts tracked within the system. This centralized approach allows NASA to reduce and leverage training costs by eliminating unique systems, standardizing training processes, and maintain valid data across the Agency. In 2018, NASA migrated SATERN to a software as a service (SaaS) cloud hosted solution.

Through SATERN, employees can view required training, launch online content, view training history, and self-register for approved courses and conferences. In addition, the system allows NASA officials to identify groups and individuals who have not met basic training requirements and ensure accountability for mission-critical and Federally mandated training and development. SATERN also offers employees access to career planning tools, individual development plans, and competency management assistance. Currently, SATERN offers learners access to more than 2,500 online courses and 18,000 online books and training videos via our partnership with SkillSoft. We are also working with other entity partnerships to enhance the overall learning experience and provide more learning opportunities. SATERN is available at all times and can be accessed from work, home or via approved mobile devices.

Recruitment One-Stop (Managing Partner OPM) FY 2023 Benefits

USAJOBS simplifies the Federal Job Search Process for Job Seekers and Agencies. The USAJOBS.gov website (see: https://www.usajobs.gov/) provides a place where citizens can search for employment opportunities throughout the Federal Government. USAJOBS is a fully operational, state-of-the-art recruitment system that simplifies the Federal job search process for job-seekers and agencies. Through USAJOBS.gov users have access to:

- A centralized repository for all competitive service job vacancies;
- Job vacancies;
- A resume repository used by agencies to identify critical skills;
- A standardized online recruitment tool and services;
- A standard application process; and
- Intuitive job searches including e-mail notifications for jobs of interest.

Integration with Recruitment One-Stop allows NASA to better attract individuals who can accomplish the Agency's mission. The USAJOBS interface allows job-seekers to view and apply for all NASA employment opportunities, as well as those from other Federal agencies.

In 2005, NASA adopted the USAJOBS resume as the basic application document for all NASA positions, except for astronaut positions. To date NASA has not identified any specific savings, either in terms of budgeted savings or cost avoidance. Although the Agency believes that implementation of Recruitment One-Stop has resulted in significant intangible benefits in terms of providing better vacancy information to applicants, it has not resulted in any specific cost savings to NASA. The numerous intangible benefits Recruitment One-Stop provides to NASA and other agencies include:

- Decreasing hiring time for managers;
- Providing an integrated solution to Agency applicant assessment systems;
- Providing a cost-effective marketing and recruitment tool;
- Realizing cost savings over commercial job posting boards;
- Reducing the delay associated with filling critical Agency vacancies; and
- Enhancing competition with the private sector for the best and brightest talent for Federal service.

Enterprise HR Integration (Managing Partner OPM) FY 2023 Benefits

The Enterprise HR Integration (EHRI) Program supports the strategic management of human capital by providing Agency customers access to timely and accurate Federal workforce data. In support of this objective, EHRI has the following goals: 1) Streamline and automate the exchange of Federal employee human resources (HR) information Government wide; 2) Provide comprehensive knowledge management and workforce analysis, forecasting, and reporting across the Executive Branch; 3) Maximize cost savings captured through automation; and 4) Enhance retirement processing throughout Executive Branch.

A key initiative of EHRI is the electronic Official Personnel Folder (eOPF), a web-based application capable of storing, processing, and displaying the OPFs of all current, separated, and retired Federal

Employees. Specific EHRI/eOPF benefits to NASA include improved convenience in searching for information, better security and safety for electronic files, decreased costs, streamlined business processes, and the ability to have a central repository of OPF records for the Agency. NASA deployed the eOPF capability of electronic transfer of eOPFs between agencies in FY 2010. Specific NASA

employee benefits include secure online access to OPFs, automatic notification when documents are added, exchange of retirement and HR data across agencies and systems, and the elimination of duplicate and repetitive personnel data in personnel folders. NASA completed its implementation to eOPF in March 2008, and transitioned personnel actions processing to the NASA Shared Service Center.

E-Payroll FY 2023 Benefits

The E-Payroll Initiative standardizes and consolidates Government-wide Federal civilian payroll services and processes by simplifying and standardizing HR/payroll policies and procedures and better integrating payroll, HR, and finance functions. Since 2004, the Department of Interior (DOI) has served as NASA's payroll provider. DOI's system (Federal Personnel and Payroll System [FPPS]) processes NASA's HR and Payroll transactions and supplies all key delivery aspects of its payroll operation functions. The E-Payroll Initiative benefits NASA by permitting the Agency to focus on its mission-related activities rather than on administrative payroll functions. Payroll processing costs are reduced through economies of scale and avoiding the cost of duplicative capital system modernization activities. The initiative also promotes standardization of business processes and practices and unified service delivery.

E-Travel (Managing Partner GSA) FY 2023 Benefits

NASA completed migration of its travel services to Electronic Government Travel System 2 (ETS2) - Concur Government Edition (CGE) (formerly HP Enterprise Services [FedTraveler]). Completed in 2014, this migration has allowed NASA to provide more efficient and effective travel management services. ETS2 is a streamlined, adaptable, world-class travel management service that continually applies commercial best practices to realize travel efficiencies and deliver a transparent, accountable, and sustainable service that yields exceptional customer satisfaction.

Integrated Award Environment (Managing Partner GSA) FY 2023 Benefits

The Integrated Award Environment (IAE) initiative is designed to support a common, secure business environment which facilitates and supports the cost-effective acquisition of and payment for goods and services; effective management of Federal acquisition and assistance awards; and consistent transparency into Federal awards. The IAE services enable NASA to do business with industry, whether it is through contracts, grants or loans, in a smart, streamlined, shared services platform. Services range from entity management, pre-award, post award, and common services (e.g., data governance, security, hosting, help desk, single sign-on, and search). Use of the IAE common services allows agencies to focus on specific needs (e.g., strategy, operations, and management), while leveraging shared services for common functions. Furthermore, use of a Government-wide business focused service environment reduces funding and resources for technical services and support for acquisition systems originally housed by individual agencies.

E-GOV INITIATIVES AND BENEFITS

Through adoption of the tools and services provided by IAE, NASA improves its ability to make informed and efficient purchasing decisions and allows it to replace manual processes. If NASA did not use IAE systems, the Agency would need to build and maintain separate systems to record vendor and contract information and to post procurement opportunities. Agency purchasing officials would not have access to databases of important information from other agencies on vendor performance and could not use systems to replace paper-based and labor-intensive work efforts.

Integrated Award and Environment – Loans & Grants FY 2023 Benefits

All agencies participating in the posting and/or awarding of Contracts and Loans & Grants are required by the Federal Funding Accountability and Transparency Act (FFATA) of 2006 and the Digital Accountability and Transparency Act of 2014 (DATA Act) reporting requirements to disclose award information on a publicly accessible website. On December 14, 2007, OMB launched USASpending.gov (see: http://www.USASpending.gov) to meet the FFATA statutory requirements. NASA analyzes the past and present total funding amounts of each proposing entity, as well as its total number of awards to assist in assessing each grant proposer's risk level and score during the 2 Code of Federal Regulations (CFR) 200 required pre-award risk assessment process. This information is submitted and housed in USASpending.gov by funding agency. Understanding the total dollar amounts managed and the number of awards provides insight on a proposer's experience with managing Federal funds.

Federal PKI Bridge - FY 2023 Benefits

The Federal Public Key Infrastructure (FPKI) is the primary, secure mechanism that allows for electronic business transactions across Government and between Government and industry. It is the backbone and trust anchor for HSPD-12 and PIV cards and is critical to enabling cyber security via identity management. The FPKI enables secure physical and logical access using strong credentials, such as the PIV card, and allows NASA documents to be digitally signed, sent, encrypted, and archived in digital media without fear that they will be compromised, spoofed, or altered. A number of core Government-wide documents mandate NASA's use of the FPKI.

LINES OF BUSINESS

Financial Management LoB (Managing Partners DOE and DOL) FY 2023 Benefits

NASA's contribution to the FM Line of Business (LoB) supports efforts to transform Federal financial management, reduce costs, increase transparency, and improve delivery of agencies' missions by operating at scale, relying on common standards, shared services, and using state-of-the-art technology. NASA benefits from the FM LoB because it provides a forum in which Federal agencies can share information and weigh pros and cons of various initiatives (e.g., shared services). A shared services solution may be an alternative considered by NASA as part of its financial system improvements.

Human Resources Management LoB (Managing Partner OPM) FY 2023 Benefits

The HR LoB vision is to create Government-wide, modern, cost-effective, standardized, and interoperable HR solutions to provide common core functionality to support the strategic management of Human Resources through the establishment of Shared Service Centers (SSCs).

E-GOV INITIATIVES AND BENEFITS

NASA works in partnership with one of the approved service providers, the Department of Interior's Business Center (IBC). Through this partnership, NASA shares and receives "best-in-class" HR solutions. The IBC delivers NASA-developed solutions to their customer agencies, enabling improved efficiencies and system integrations at a fraction of the cost and delivery time of similar solutions that could have been produced by the Interior Business Center. NASA achieves the benefits of "best- in-class" HR solutions through the implementation and integration of IBC and NASA-developed HR solutions. NASA's participation in the HR LoB provides the Agency opportunities to implement

modern HR solutions and benefit from Government-wide strategic HR management best practices. NASA participates in the ongoing development of a 10-year Federal Human Resources Strategic Plan with the HR LoB managing partner (OPM) and member agencies.

Geospatial LoB (Managing Partner DOI) FY 2023 Benefits

The Geospatial LoB was sunset when OMB released the Federal IT Shared Services Strategy in 2012. However, NASA continues to be active in the Federal Geographic Data Committee (FGDC) and supports FGDC standards wherever applicable. NASA also continues to provide support and data to the Geoplatform and supports three National Geospatial Data Assets in partnership with USGS.

Budget Formulation & Execution LOB (Managing Partner Education) FY 2023 Benefits

The Budget Formulation and Execution LoB (BFELoB) provides significant benefits to NASA and other partner agencies by encouraging best practices crossing all aspects of Federal budgeting – from budget formulation and execution to performance to human capital needs. To benefit all agencies, BFELoB continues to support the idea of shared service budget systems. As NASA currently has its own budgeting tools, the Agency has not chosen to move to a new budget system; however, a shared service budget system is an option in the future.

COMPARABILITY ADJUSTMENT TABLES

FY 2021 Budget Structure Crosswalk to FY 2023 Budget Structure Budget Authority ($ in millions)	FY 2021 Structure	FY 2023 Structure
NASA TOTAL	**$25,246.0**	**$25,246.0**
Deep Space Exploration Systems	**$8,761.7**	**$8,621.7**
Exploration Systems Development - renamed Common Exploration Systems Development	**$4,042.3**	**$4,042.3**
Exploration Research & Development - renamed Artemis Campaign Development	**$4,719.4**	**$4,321.2**
Advanced Exploration Systems	$258.2	
Gateway	$739.3	$564.0
Gateway	*$739.3*	*$564.0*
Surface Suits	$175.3	
Adv Cislunar and Surface Capabilities	$212.1	$212.1
Human Research Program	$140.0	
Human Landing System	$3,369.8	$3,369.8
xEVA and Human Surface Mobility Program		$175.3
Shutdown and other Agency Admin		*$175.3*
Surface Suits		$175.3
Mars Campaign Development		**$258.2**
Exploration Capabilities		$258.2
Advanced Exploration Systems		*$258.2*
Exploration Technology - renamed Space Technology	**$1,578.3**	**$1,578.3**
Exploration Technology - renamed Space Technology	**$1,578.3**	**$1,578.3**
Early Stage Innovation and Partnerships	$169.2	$169.2
Technology Maturation	$469.1	$469.1
Technology Demonstration	$537.2	$537.2
Laser Comm Relay Demo (LCRD)	*$13.6*	
OSAM-1	*$133.5*	*$133.5*
Solar Electric Propulsion (SEP)	*$48.7*	*$48.7*
Small Spacecraft, Flight Opportunities & Other Tech Demo	*$341.4*	*$355.0*
TDM Laser Comm Relay Demo (LCRD)		$13.6
SBIR and STTR	$402.8	$402.8
LEO and Spaceflight Operations - renamed Space Operations	**$4,187.3**	**$4,327.3**
International Space Station	**$1,400.7**	**$1,400.7**
Space Transportation	**$1,877.8**	**$1,876.8**
Crew and Cargo Program	$1,778.1	$1,778.1
Commercial Crew Program	$99.7	$98.7
Commercial Crew	*$99.7*	*$98.7*
Commercial Space Capabilities	$1.1	
Space and Flight Support (SFS)	**$758.7**	**$898.7**
Space Communications and Navigation	$506.0	$506.0
Human Space Flight Operations	$89.9	$89.9
Launch Services	$91.9	$91.9
Rocket Propulsion Test	$47.6	$47.6
Communications Services Program	$23.4	$23.4
Human Research Program		$140.0
Commercial LEO Development	**$150.0**	**$151.1**
Commercial LEO Development Program	$150.0	$151.1
Commercial LEO Development	*$150.0*	*$151.1*
Commercial Space Capabilities		$1.1
Science	**$6,306.5**	**$6,306.5**
Earth Science	**$1,768.1**	**$1,768.1**
Earth Science Research	$447.3	$447.3
Earth Systematic Missions	$608.3	$608.3
Surface Water and Ocean Topography	*$63.9*	*$63.9*
NASA-ISRO SAR	*$59.7*	*$59.7*

COMPARABILITY ADJUSTMENT TABLES

FY 2021 Budget Structure Crosswalk to FY 2023 Budget Structure Budget Authority ($ in millions)	FY 2021 Structure	FY 2023 Structure
Landsat 9	*$86.5*	
Sentinel-6	*$20.4*	
Other Missions and Data Analysis	*$377.8*	*$464.4*
Landsat 9		$86.5
Earth System Science Pathfinder	$338.9	$313.9
Venture Class Missions	*$263.6*	*$201.4*
Multi-Angle Imager for Aerosols	$16.8	
GeoCarb	$45.4	
Multi-Angle Imager for Aerosols		*$16.8*
GeoCarb		*$45.4*
Other Missions and Data Analysis	*$75.3*	*$50.3*
Commercial SmallSat Data Acquisition	$25.0	
Earth Science Data Systems	$245.4	$270.4
Earth Science Data Systems (ESDS)	*$245.4*	*$270.4*
Commercial SmallSat Data Acquisition		$25.0
Earth Science Technology	$74.2	$74.2
Applied Sciences	$53.9	$53.9
Planetary Science	**$2,659.6**	**$2,659.6**
Planetary Science Research	$305.4	$305.4
Planetary Defense	$150.0	$150.0
DART	*$66.4*	
Other Missions and Data Analysis	*$83.6*	*$150.0*
Double Asteroid Redirection Test		$66.4
Lunar Discovery and Exploration	$451.5	$451.5
VIPER		*$67.5*
Other Missions and Data Analysis	*$451.5*	*$384.0*
Volatiles Investiga Polar Explortn Rover	$67.5	
Discovery	$484.3	$484.3
Lucy	*$153.4*	
Psyche	*$187.4*	*$187.4*
Other Missions and Data Analysis	*$143.5*	*$296.9*
Lucy		$153.4
New Frontiers	$179.0	$179.0
Mars Exploration	$528.5	$528.5
Mars Rover 2020	*$162.3*	
Other Missions and Data Analysis	*$366.2*	*$528.5*
Mars Rover 2020		$162.3
Outer Planets and Ocean Worlds	$414.4	$414.4
Radioisotope Power	$146.3	$146.3
Astrophysics	**$831.0**	**$1,245.7**
Astrophysics Research	$269.7	$269.7
Cosmic Origins	$124.0	$538.7
James Webb Space Telescope		*$414.7*
Hubble Space Telescope (HST)	*$88.3*	*$88.3*
Stratospheric Observatory for Infrared Astronomy (SOFIA)	*$12.0*	
Other Missions and Data Analysis	*$23.7*	*$35.7*
Stratospheric Observatory for Infrared Astronomy (SOFIA)		$12.0
Physics of the Cosmos	$143.9	$143.9
Exoplanet Exploration	$47.2	$47.2
Astrophysics Explorer	$246.2	$246.2
SPHEREx		*$90.8*
Other Missions and Data Analysis	*$246.2*	*$155.4*
Spectro-Photometer for the History of th	$90.8	

COMPARABILITY ADJUSTMENT TABLES

FY 2021 Budget Structure Crosswalk to FY 2023 Budget Structure Budget Authority ($ in millions)	FY 2021 Structure	FY 2023 Structure
Heliophysics	**$633.1**	**$633.1**
Heliophysics Research	$230.5	$230.5
Living with a Star	$127.9	$113.3
Solar Orbiter Collaboration	*$8.1*	
Other Missions and Data Analysis	*$119.7*	*$113.3*
Solar Orbiter Collaboration		$8.1
Space Weather Science and Applications	$14.6	
Solar Terrestrial Probes	$126.3	$126.3
Interstellar Mapping and Acceleration Probe (IMAP)		*$72.6*
Other Missions and Data Analysis	*$126.3*	*$53.7*
Interstellar Mapping and Acceleration Pr	$72.6	
Heliophysics Explorer Program	$148.4	$148.4
Space Weather		$14.6
Space Weather		*$14.6*
Space Weather Science and Applications		$14.6
James Webb Space Telescope	**$414.7**	
Aeronautics	**$819.0**	**$819.0**
Aeronautics	**$819.0**	**$819.0**
Airspace Operations and Safety Program	$90.4	$135.4
Airspace Operations and Safety Program	*$90.4*	*$135.4*
Advanced Air Mobility		$45.0
Advanced Air Vehicles Program	$212.7	$212.7
Integrated Aviation Systems Program	$269.0	$224.0
Low Boom Flight Demonstrator	*$79.1*	*$79.1*
Electrified Powertrain Flight Demonstration		*$85.3*
Integrated Aviation Systems Program	*$190.0*	*$59.7*
Electric Powertrain Flight Demonstration	$85.3	
Advanced Air Mobility	$45.0	
Transformative Aero Concepts Program	$129.9	$129.9
Aerosciences Eval. & Test Capab. Program	$117.0	$117.0
STEM Engagement	**$0.0**	**$0.0**
Safety, Security, and Mission Services	**$3,009.9**	**$3,009.9**
Construction & Envrmtl Compl Restoration	**$539.1**	**$539.1**
Inspector General	**$44.2**	**$44.2**
NASA TOTAL	**$25,246.0**	**$25,246.0**

NOTE: Chart represents changes in budget structure and does not reflect funding changes.

COMPARABILITY ADJUSTMENT TABLES

FY 2022 Budget Structure Crosswalk to FY 2023 Budget Structure Budget Authority ($ in millions)	FY 2022 Structure	FY 2023 Structure
NASA TOTAL	**$24,801.5**	**$24,801.5**
Deep Space Exploration Systems	**$6,880.4**	**$6,750.2**
Exploration Systems Development - renamed Common Exploration Systems Development	**$4,483.7**	**$4,483.7**
Exploration Research & Development - renamed Artemis Campaign Development	**$2,396.7**	**$2,062.0**
Advanced Exploration Systems	$195.0	
Gateway	$785.0	$685.0
Gateway	*$785.0*	*$685.0*
xEVA Surface Suits	$100.0	
Adv Cislunar and Surface Capabilities	$91.5	$82.0
Adv Cislunar and Surface Capabilities	*$91.5*	*$82.0*
Moon and Mars Architecture	$9.5	
Human Research Program	$130.2	
Human Landing System	$1,195.0	$1,195.0
xEVA and Human Surface Mobility Program		$100.0
Shutdown and other Agency Admin		***$100.0***
xEVA Surface Suits		$100.0
Human Exp Requirements & Architecture		**$9.5**
Moon & Mars Architecture		$9.5
Shutdown and other Agency Admin		*$9.5*
Moon and Mars Architecture		$9.5
Mars Campaign Development		**$195.0**
Exploration Capabilities		$195.0
Advanced Exploration Systems		*$195.0*
Space Technology	**$1,425.0**	**$1,425.0**
Space Operations	**$4,017.4**	**$4,147.6**
International Space Station	**$1,327.6**	**$1,327.6**
Space Transportation	**$1,771.7**	**$1,770.2**
Crew and Cargo Program	$1,617.2	$1,617.2
Commercial Crew Program	$154.5	$153.0
Commercial Crew	*$154.5*	*$153.0*
Commercial Space Capabilities	$1.5	
Space and Flight Support (SFS)	**$817.0**	**$947.2**
Space Communications and Navigation	$522.6	$522.6
Human Space Flight Operations	$101.8	$101.8
Launch Services	$102.7	$102.7
Rocket Propulsion Test	$47.8	$47.8
Communications Services Program	$42.0	$42.0
Human Research Program		$130.2
Commercial LEO Development	**$101.1**	**$102.6**
Commercial LEO Development Program	$101.1	$102.6
Commercial LEO Development	*$101.1*	*$102.6*
Commercial Space Capabilities		$1.5
Science	**$7,931.4**	**$7,931.4**
Earth Science	**$2,250.0**	**$2,250.0**
Earth Science Research	$537.5	$537.5
Earth Systematic Missions	$836.1	$836.1
Surface Water and Ocean Topography	*$32.8*	*$32.8*
NASA-ISRO SAR	*$73.3*	*$73.3*

COMPARABILITY ADJUSTMENT TABLES

FY 2022 Budget Structure Crosswalk to FY 2023 Budget Structure Budget Authority ($ in millions)	FY 2022 Structure	FY 2023 Structure
Landsat 9	*$2.8*	
Sentinel-6	*$22.8*	*$22.8*
PACE	*$119.4*	*$119.4*
Other Missions and Data Analysis	*$585.0*	*$587.8*
Landsat 9		$2.8
Earth System Explorers	$6.6	$6.6
Earth System Science Pathfinder	$375.3	$375.3
Venture Class Missions	*$326.9*	*$253.5*
Multi-Angle Imager for Aerosols	$16.2	
GeoCarb	$57.2	
Multi-Angle Imager for Aerosols		*$16.2*
GeoCarb		*$57.2*
Other Missions and Data Analysis	*$48.4*	*$48.4*
Earth Science Data Systems	$330.7	$330.7
Earth Science Technology	$91.1	$91.1
Applied Sciences	$72.7	$72.7
Planetary Science	**$3,200.0**	**$3,200.0**
Planetary Science Research	$306.9	$306.9
Planetary Defense	$197.2	$197.2
DART	*$11.1*	
NEO Surveyor		*$143.2*
Other Missions and Data Analysis	*$186.1*	*$54.0*
Near Earth Objects Surveyor	$143.2	
Double Asteroid Redirection Test		$11.1
Lunar Discovery and Exploration	$497.3	$497.3
Mars Sample Return	$653.2	$653.2
Discovery	$364.8	$364.8
Lucy	*$77.3*	
Psyche	*$139.7*	*$139.7*
Other Missions and Data Analysis	*$147.8*	*$225.0*
Lucy		$77.3
New Frontiers	$271.7	$271.7
Mars Exploration	$267.8	$267.8
Outer Planets and Ocean Worlds	$494.8	$494.8
Radioisotope Power	$146.4	$146.4
Astrophysics	**$1,400.2**	**$1,575.6**
Astrophysics Research	$285.5	$285.5
Cosmic Origins	$115.0	$290.4
James Webb Space Telescope		*$175.4*
Hubble Space Telescope (HST)	*$98.3*	*$98.3*
Other Missions and Data Analysis	*$16.7*	*$16.7*
Physics of the Cosmos	$156.0	$156.0
Exoplanet Exploration	$543.3	$543.3
Astrophysics Explorer	$300.4	$300.4
Heliophysics	**$796.7**	**$796.7**
Heliophysics Research	$210.6	$210.6

COMPARABILITY ADJUSTMENT TABLES

FY 2022 Budget Structure Crosswalk to FY 2023 Budget Structure Budget Authority ($ in millions)	FY 2022 Structure	FY 2023 Structure
Living with a Star	$115.3	$98.8
Other Missions and Data Analysis	*$115.3*	*$98.8*
Space Weather Science and Applications	$9.9	
Heliophysics Environmental & Radiation M	$6.5	
Solar Terrestrial Probes	$253.3	$253.3
Heliophysics Explorer Program	$189.2	$189.2
Heliophysics Technology	$28.3	$28.3
Space Weather		$16.5
Space Weather		*$16.5*
Space Weather Science and Applications		$9.9
Heliophysics Environmental & Radiation M		$6.5
James Webb Space Telescope	**$175.4**	
Biological and Physical Sciences	**$109.1**	**$109.1**
Aeronautics	**$914.8**	**$914.8**
Aeronautics	**$914.8**	**$914.8**
Airspace Operations and Safety Program	$104.5	$147.4
Airspace Operations and Safety Program	*$104.5*	*$147.4*
Advanced Air Mobility		$42.9
Advanced Air Vehicles Program	$243.7	$243.7
Integrated Aviation Systems Program	$301.5	$258.6
Electrified Powertrain Flight Demonstration	*$91.2*	*$91.2*
Low Boom Flight Demonstrator	*$74.6*	*$74.6*
Integrated Aviation Systems Program	*$135.7*	*$92.8*
Advanced Air Mobility	$42.9	
Transformative Aero Concepts Program	$148.0	$148.0
Aerosciences Eval. & Test Capab. Program	$117.0	$117.0
STEM Engagement	**$147.0**	**$147.0**
Safety, Security, and Mission Services	**$3,049.2**	**$3,049.2**
Construction & Envrmtl Compl Restoration	**$390.3**	**$390.3**
Inspector General	**$46.0**	**$46.0**
NASA TOTAL	**$24,801.5**	**$24,801.5**

NOTE: Chart represents changes in budget structure and does not reflect funding changes.

RE-BASELINED PROJECTS

FY 2023 Congressional Justification

Original Agency Baseline Commitments vs Re-baseline Life Cycle Calculation Section

As part of the NASA corrective action plan related to the GAO high risk list, rebaselined projects are reported periodically to Congress, GAO and OMB. For projects that have been re-baselined due to performance (vice scope change), and for transparency purposes, NASA includes original cost and schedule Agency Baseline Commitments (ABCs) in our quarterly, semi-annual, and annual external cost and schedule reports alongside the current rebaselined life-cycle costs.

Please note that OSAM-1 is not included below because a review is currently underway to determine the complete impact on the project. An initial notification has been sent to Congress, stating OSAM-1 would exceed its cost/schedule thresholds. NASA OCFO plans to follow the aforementioned reporting approach for this project once re-baselined.

Exploration Ground Systems (EGS)	Date	Prior	FY20	FY21	FY22	FY23	FY24	FY25	FY26	BTC	Total
Original Life Cycle Cost	2014	2,813	-	-	-	-	-	-	-	-	2,813
Rebaselined Life Cycle Cost	2020	3,039	166	193	16	-	-	-	-	-	3,413

James Webb Space Telescope (Webb)	Date	Prior	FY20	FY21	FY22	FY23	FY24	FY25	FY26	BTC	Total
Original Life Cycle Cost	2009	4,821	76	54	12	-	-	-	-	-	4,964
Rebaselined Life Cycle Cost	2019	8,018	423	415	175	172	172	172	115	-	9,663

Laser Communications Relay Demonstration (LCRD)	Date	Prior	FY20	FY21	FY22	FY23	FY24	FY25	FY26	BTC	Total
Original Life Cycle Cost	2017	263	-	-	-	-	-	-	-	-	263
Rebaselined Life Cycle Cost	2020	263	31	17	-	-	-	-	-	-	310

Orion	Date	Prior	FY20	FY21	FY22	FY23	FY24	FY25	FY26	BTC	Total
Original Life Cycle Cost	2015	9,392	828	649	293	121	-	-	-	-	11,283
Rebaselined Life Cycle Cost	2021	10,145	1,235	970	809	404	156	92	-	-	13,811

Space Launch System (SLS)	Date	Prior	FY20	FY21	FY22	FY23	FY24	FY25	FY26	BTC	Total
Original Life Cycle Cost	2014	9,695	-	-	-	-	-	-	-	-	9,695
Rebaselined Life Cycle Cost	2020	10,654	511	464	154	-	-	-	-	-	11,782

Solar Electric Propulsion (SEP)	Date	Prior	FY20	FY21	FY22	FY23	FY24	FY25	FY26	BTC	Total
Original Life Cycle Cost	2020	246	-	49	25	9	6	-	-	-	336
Rebaselined Life Cycle Cost	2022	246	-	32	30	21	22	20	6	6	382

Pursuant to Section 103(e) of P.L. 109-155, this budget request establishes a new baseline for SEP. The original SEP baseline in 2020 had a 30 percent development cost increase and a 46-month schedule increase.

COST AND SCHEDULE PERFORMANCE SUMMARY

2022 Major Program Annual Report Summary

The 2022 Major Program Annual Report (MPAR) is provided to meet the requirements of section 103 of the NASA Authorization Act of 2005 (P.L. 109-155; 42 U.S.C. 16613). The 2022 MPAR consists of this summary and FY 2023 Congressional Justification pages designated as "Projects in Development," for the projects outlined below. These project pages constitute each project's annual report, or if this is the first year for which it is in reporting, the baseline report. The MPAR summary also includes the confidence level of achieving the commitments as requested in the Conference Report accompanying the FY 2010 Consolidated Appropriations Act (P.L. 111-117).

Changes in MPAR Composition since the FY 2022 NASA Budget Estimates

There is one new project, Interstellar Mapping and Acceleration Probe (IMAP), with an estimated lifecycle cost greater than $250 million that received authority to proceed into the development phase since NASA submitted its 2021 MPAR in the FY 2022 NASA Congressional Justification. Two projects, Geostationary Carbon Observatory (GeoCarb) and Multi-Angle Imager for Aerosols (MAIA), have experienced cost growth since mission confirmation such that their estimated lifecycle costs now exceed $250 million. These missions will now be included in the MPAR report.

- The IMAP project with a baseline development cost of $589.5 million and a joint confidence level of 70 percent.
- The GeoCarb project baseline development costs are currently under review and were not approved prior to publication of the Congressional Justification. FY 2022 budget estimates are provided in Figure 1; NASA will notify Congress when a new project baseline has been approved by the Agency.
- The MAIA project baseline development costs are currently under review and were not approved prior to publication of the Congressional Justification. FY 2022 budget estimates are provided in the table below; NASA will notify Congress when a new project baseline has been approved by the Agency.

Changes in Development Cost and Schedule Estimates from the 2021 MPAR

There are five projects that had no changes in their development cost or schedule estimates over the last year. Psyche, Sentinel-6, Spectro-Photometer for the History of the Universe, Epoch of Reionization and IcesExplorer (SPHEREx), Volatiles Investigating Polar Exploration Rover (VIPER), and NASA-ISRO Synthetic Aperture Radar (NISAR).

The Orion project has been rebaselined with development cost increases and a revised launch readiness date (LRD). The Europa Clipper development cost increased 4 percent with no change to schedule. The Space Launch System (SLS) project experienced a 3-month schedule delay with no development cost impacts.

There are six projects with development cost increases and schedule delays. The percentages and schedule delays below are not reflected in Figure 1 in all cases since they are deltas from last year's MPAR submission.

1. Exploration Ground Systems (EGS) development cost increased by 4 percent with a 3-month schedule delay.
2. Low-Boom Flight Demonstrator (LBFD) development cost increased by 8 percent with a 6-month schedule delay.

3. Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) development cost increased by 10 percent with a 4-month schedule delay.
4. Roman development cost increased by 12 percent with a 7-month schedule delay.
5. Surface Water and Ocean Topography (SWOT) development cost increased by 12 percent with a 14-month schedule delay.
6. On-Orbit Servicing, Assembly, and Manufactring-1 (OSAM-1) is expected to exceed the baseline schedule milestone by more than 6 months and the baseline development cost by more than 15 percent. An initial notification has been sent to Congress, stating OSAM-1 would exceed its cost/schedule thresholds. A review is currently underway to determine the complete impact on the project.

MPAR Summary Table

Figure 1 provides cost, schedule, and confidence level information for NASA projects currently in development with lifecycle cost estimates of $250 million or more. NASA records the estimated development cost and a key schedule milestone and then measures changes from them. NASA tracks one of several key milestones, listed below, for reporting purposes:

- initial operating capability (IOC);
- full operational capability (FOC);
- launch readiness date (LRD); or
- launch readiness for Artemis I or Artemis II.

As a note for clarification, LRD schedule milestones, as reported here, are not typically the launch dates on the NASA launch manifest, but are the desired launch dates as determined by the payload mission and approved by the NASA Flight Planning Board (FPB). A launch manifest is a dynamic schedule that is affected by real world operational activities conducted by NASA and multiple other entities. It reflects the results of a complex process that requires the coordination and cooperation by multiple users for the use of launch range and launch contractor assets. The launch dates shown on the NASA FPB launch manifest are a mixture of confirmed range dates for missions launching within approximately six months and contractual/planning dates for the missions beyond six months from launch. The NASA FPB launch manifest date is typically earlier than the reported schedule dates reported here, thereby allowing for the operationally driven fluctuations to the launch schedule that may be outside of the project's control. The NASA FPB launch manifest is updated on a periodic basis throughout the year.

Additional explanations for the data in the summary table are provided here:

- SLS and EGS: The Artemis I launch date is under review pending completion of Wet Dress Rehearsal currently scheduled for March 2022. The cost estimate includes Construction of Facilities funds.
- Webb: Cost Estimate includes Construction of Facilities funds.
- EGS: The 80 percent joint confidence level (JCL) is inferred from analysis based on FY 2014 President's Budget Request (PBR) including FY 2014 Appropriation changes. JCL analysis was completed prior to the release of the FY 2015 PBR. The Agency baseline commiemtn (ABC) is informed by the 80 percent JCL and adjusted to reflect the FY 2015 PBR budget reduction.

Additional information on the projects shown in the table below can be found in their individual program and project pages.

COST AND SCHEDULE PERFORMANCE SUMMARY

Figure 1: MPAR Summary and Confidence Levels

Project	Base Year	JCL (%)	Development Cost Estimate ($M)		Cost Change (%)	Key Milestone Event	Key Milestone Date		Schedule Change (months)
			Baseline	FY 2022			Baseline	FY 2022	
EGS**	2015	80	2,438.4	2,592.5	6%	LR for Artemis I	Nov 2021	May 2022	6
Europa Clipper	2020	N/A	2,412.8	2,478.4	3%	LRD	Sep 2025	Sep 2025	0
GeoCarb	2022	TBD	TBD	269.4	N/A	LRD	TBD	TBD	N/A
IMAP	2022	70	589.5	589.5	0%	LRD	Dec 2025	Dec 2025	0
LBFD	2018	70	467.7	572.2	22%	First Flight	Jan 2022	Dec 2022	11
MAIA	2022	TBD	TBD	227.1	N/A	LRD	TBD	TBD	N/A
NISAR	2017	70	661.0	774.3	17%	LRD	Sep 2022	Sep 2023	12
Orion***	2016	70	9,301.2	9,301.2	0%	LR for Artemis II	May 2024	May 2024	0
OSAM-1*	2021	70	974.4	TBD	TBD	LRD	Sep 2025	TBD	TBD
PACE	2020	70	558.0	632.3	13%	LRD	Jan 2024	May 2024	4
Psyche	2020	70	681.9	651.1	-5%	LRD	Aug 2022	Aug 2022	0
Roman	2021	70	2,898.1	3,270.0	13%	LRD	Oct 2026	May 2027	7
Sentinel-6	2017	70	465.9	402.3	-14%	LRD	Nov 2021	Nov 2021	0
SEP++	2022	N/A	203.2	203.2	0%	EPT Life Qual Test Report	Oct 2028	Oct 2028	0
SLS	2015	70	9,108.3	9,108.3	0%	LR for Artemis I	Nov 2021	May 2022	6
SPHEREx	2021	70	367.8	367.8	0%	LRD	Apr 2025	Apr 2025	0
SWOT	2017	80	571.5	639.0	12%	LRD	Apr 2022	Jun 2023	14
VIPER	2021	70	336.2	336.2	0%	IOC	Nov 2023	Nov 2023	0
Webb	2012	70	7,002.6	7,117.1	2%	LRD	Mar 2021	Dec 2021	9

COST AND SCHEDULE PERFORMANCE SUMMARY

** OSAM-1 An initial notification has been sent to Congress, stating OSAM-1 would exceed its cost/schedule thresholds. A review is currently underway to determine the complete impact on the project.*

*** The 80% JCL is inferred from analysis based on FY 2014 President's Budget Request (PBR) including FY 2014 Appropriation changes. JCL analysis was completed prior to the release of the FY 2015 PBR. The ABC is informed by the 80% JCL and adjusted to reflect the FY 2015 PBR budget reduction.*

**** Approximately -2% of this amount reflects a transfer of funding to formulation costs and does not represent a reduction in the life cycle cost estimates.*

++ Pursuant to sec. 103(e) of P.L. 109-155, this budget request establishes a new baseline for SEP. The original SEP baseline in 2020 had a 30% development cost increase.

Launch Readiness (LR) Launch Readiness Date (LRD) Advanced Electric Propulsion System (AEPS)

FY 2023 PROPOSED APPROPRIATIONS LANGUAGE

DEEP SPACE EXPLORATION SYSTEMS

For necessary expenses, not otherwise provided for, in the conduct and support of exploration research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $7,478,283,000, to remain available until September 30, 2024.

SPACE OPERATIONS

For necessary expenses, not otherwise provided for, in the conduct and support of space operations research and development activities, including research, development, operations, support and services; space flight, spacecraft control, and communications activities, including operations, production, and services; maintenance and repair, facility planning and design; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $4,266,317,000, to remain available until September 30, 2024.

SPACE TECHNOLOGY

For necessary expenses, not otherwise provided for, in the conduct and support of space technology research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $1,437,900,000, to remain available until September 30, 2024.

SCIENCE

For necessary expenses, not otherwise provided for, in the conduct and support of science research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $7,988,300,000, to remain available until September 30, 2024.

AERONAUTICS

For necessary expenses, not otherwise provided for, in the conduct and support of aeronautics research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $971,500,000, to remain available until September 30, 2024.

FY 2023 Proposed Appropriations Language

Science, Technology, Engineering, and Mathematics Engagement

For necessary expenses, not otherwise provided for, in the conduct and support of aerospace and aeronautical education research and development activities, including research, development, operations, support, and services; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $150,100,000, to remain available until September 30, 2024.

Safety, Security, and Mission Services

For necessary expenses, not otherwise provided for, in the conduct and support of science, aeronautics, space technology, exploration, space operations and education research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of zero emissions passenger motor vehicles- and supporting charging or fueling infrastructure; not to exceed $63,000 for official reception and representation expenses; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $3,208,700,000, to remain available until September 30, 2024.

Construction and Environmental Compliance and Restoration

For necessary expenses for construction of facilities including repair, rehabilitation, revitalization, and modification of facilities, construction of new facilities and additions to existing facilities, facility planning and design, and restoration, and acquisition or condemnation of real property, as authorized by law, and environmental compliance and restoration, $424,300,000, to remain available until September 30, 2028: Provided, That proceeds from leases deposited into this account shall be available for a period of 5 years to the extent and in amounts as provided in annual appropriations Acts: Provided further, That such proceeds referred to in the preceding proviso shall be available for obligation for fiscal year 2023 in an amount not to exceed $25,000,000: Provided further, That each annual budget request shall include an annual estimate of gross receipts and collections and proposed use of all funds collected pursuant to section 20145 of title 51, United States Code.

Office Of Inspector General

For necessary expenses of the Office of Inspector General in carrying out the Inspector General Act of 1978, $48,400,000, to remain available until September 30, 2024.

FY 2023 PROPOSED APPROPRIATIONS LANGUAGE

ADMINISTRATIVE PROVISIONS

Funds for any announced prize otherwise authorized shall remain available, without fiscal year limitation, until a prize is claimed or the offer is withdrawn.

Not to exceed 5 percent of any appropriation made available for the current fiscal year for the National Aeronautics and Space Administration in this Act may be transferred between such appropriations, but no such appropriation, except as otherwise specifically provided, shall be increased by more than 10 percent by any such transfers. Any funds transferred to "Construction and Environmental Compliance and Restoration" for construction activities shall not increase that account by more than 20 percent. Balances so transferred shall be merged with and available for the same purposes and the same time period as the appropriations to which transferred. Any transfer pursuant to this provision shall be treated as a reprogramming of funds under section 504 of this Act and shall not be available for obligation except in compliance with the procedures set forth in that section.

Not to exceed 5 percent of any appropriation provided for the National Aeronautics and Space Administration under previous appropriations Acts that remains available for obligation or expenditure in fiscal year 2023 may be transferred between such appropriations, but no such appropriation, except as otherwise specifically provided, shall be increased by more than 10 percent by any such transfers. Any transfer pursuant to this provision shall retain its original availability and shall be treated as a reprogramming of funds under section 504 of this Act and shall not be available for obligation except in compliance with the procedures set forth in that section.

The spending plan required by this Act shall be provided by the National Aeronautics and Space Administration at the theme and program level. The spending plan, as well as any subsequent change of an amount established in that spending plan that meets the notification requirements of section 504 of this Act, shall be treated as a reprogramming under section 504 of this Act and shall not be available for obligation or expenditure except in compliance with the procedures set forth in that section.

Of the amounts provided for Orion Multi-purpose Crew Vehicle, up to $718,000,000 may be transferred to Space Operations for Orion Production and Operations consistent with direction provided in the explanatory statement accompanying this Act. The authority provided by this paragraph is in addition to the authority provided by the second paragraph under this heading.

Not more than 20 percent or $25,000,000, whichever is less, of the amounts made available in the current-year CECR appropriation may be applied to CECR projects funded under previous years' CECR appropriation Acts. Use of current-year funds under this provision shall be treated as a reprogramming of funds under section 504 of this act and shall not be available for obligation except in compliance with the procedures set forth in that section.

Section 30102(b) of title 51, United States Code, is amended by:

(1) Redesignating existing paragraph (3) to (4); and

(2) Inserting, after paragraph (2), the following:

(3) INFORMATION TECHNOLOGY (IT) MODERNIZATION. The fund shall also be available for the purpose of funding IT Modernization activities, as described in section 1077(b)(3)(A)-(E) of Public Law 115–91, on a non-reimbursable basis.

Not to exceed $18,162,000 made available for the current fiscal year in this Act within "Safety, Security and Mission Services" may be transferred to the Working Capital Fund of the National Aeronautics and Space Administration. Balances so transferred shall be available until expended only for activities described in section 30102(b)(3) of title 51, United States Code, as amended by this Act, and shall remain available until expended. Any transfer pursuant to this provision shall be treated as a reprogramming of funds under section 504 of this Act and shall not be available for obligation except in compliance with the procedures set forth in that section.

ACRONYMS AND ABBREVIATIONS

4BCO2	Four Bed Carbon Dioxide Scrubber
AA	Associate Administrator
AAM	Advanced Air Mobility
AANAPISI	Asian American and Native American Pacific Islander-Serving Institutions
AAO	Agency Applications Office
AATT	Advanced Air Transport Technology
AAVP	Advanced Air Vehicles Program
ABC	Agency Baseline Commitment
ACAWS	Advanced Caution and Warning System
ACC	Advanced Composites Consortium
ACCESS	Advancing Collaborative Connections for Earth System Science
ACD	Artemis Campaign Development
ACE	Advanced Composition Explorer
ACES	Agency Consolidated End-User Services
ACF	Analytic Center Framework
ACMO	Aircraft Capability Management Office
ACO	Announcement of Collaboration Opportunity
ACS3	Advanced Composite Solar Sail System
ACSC	Advanced Cislunar Surface Capabilities
ACT	Advanced Component Technologies
ACTIVATE	Aerosol Cloud Meteorology Interactions over the Western Atlantic Experiment
ADAP	Astrophysics Data Analysis Program
ADCAR	Astrophysics Data Curation and Archival Research
ADS	Astrophysics Data System
AE	Auroral Electrojet
AEGIS	Agency Enterprise Global Information Technology Solutions
AEP	Annual Evaluation Plan
AEPS	Advanced Electric Propulsion System
AETC	Aerosciences Evaluation and Test Capabilities
AFC	Alternate Fecal Container
AFOSR	Air Force Office of Scientific Research
AFRC	Armstrong Flight Research Center
AFRL	Air Force Research Laboratory
AFSS	Autonomous Flight Safety System
AFTS	Autonomous Flight Termination System
AGAGE	Advanced Global Atmospheric Gases Experiment
AHU	Air Handle Units
AI	Artificial Intelligence
AI&T	Assembly, Integration, and Testing
AIAA	American Institute of Aeronautics and Astronautics

ACRONYMS AND ABBREVIATIONS

AIHEC	American Indian Higher Education Consortium
AIM	Aeronomy of Ice in the Mesosphere
AIRB	AMMOS Independent Review Board
AIRS	Atmospheric Infrared Sounder
AISES	American Indian Science and Engineering Society
AIST	Advanced Information Systems Technology
AITE	Alternative Initiation of Technology Exploration
ALMA	Atacama Large Millimeter Array
AM	Additive Manufacturing
AMMOS	Advanced Multi-Mission Operation System
AMP	Agency Master Plan
ANGSA	Apollo Next Generation Sample Analysis
ANNH	Alaska Native and Native Hawaiian
AO	Announcement of Opportunity
AOSP	Airspace Operations and Safety Program
APL	Applied Physics Laboratory
APMC	Agency Project Management Council
APMS	Ames Power Management System
ARC	Ames Research Center
ARCSIX	Arctic Radiation-Cloud-Aerosol-Surface Interaction Experiment
ARIEL	Atmospheric Remote-sensing Infrared Exoplanet
ARMD	Aeronautics Research Mission Directorate
ARSET	Applied Remote Sensing Training
ASAP	Aerospace Safety Advisory Panel
ASCAN	Astronaut Candidate
ASI	Agenzia Spaziale Italiana (Italian Space Agency)
ASIC	Application Specific Integrated Circuit
ASKAP	Australian Square Kilometre Array Pathfinder
ASM	Acquisition Strategy Meeting
ASMPM	Astrophysics Strategic Mission Program Management
ASU	Arizona State University
ATA	Agency Technical Authority
ATD	Airspace Technology Demonstration
ATF	Armstrong Test Facility
ATLAS	Advanced Topographic Laser Altimeter System
ATLO	Assembly, Test, and Launch Operations
AU	Astronomical Units
AURA	Association of Universities for Research in Astronomy
AWE	Atmospheric Wave Experiment
AWS	Amazon Web Services

ACRONYMS AND ABBREVIATIONS

BAA	Broad Agency Announcement
BARDA	Biomedical Advanced Research and Development Authority
BART	Basic Aerodynamic Research Tunnel
BCT	Blue Canyon Technologies
BFF	BioFabrication Facility
BI	Business Intelligence
BMGG	Bulk Metallic Glass Gear
BOLE	Booster Obsolescence and Life Extension
BPA	Brine Processor Assembly
BPOC	Booster Production and Operation Control
BPS	Biological and Physical Sciences
BRE	Burning Rate Emulator
BWG	Beam Waveguide
C3	Command, Control, Communication
CADRE	Cooperative Autonomous Distributed Robotic Exploration
CAL	Cold Atom Laboratory
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation
CAPSTONE	Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment
CARES	Coronavirus Aid, Relief, and Economic Security
CAS	Convergent Aeronautics Solutions
CASA	Crew Alternative Sleeping Accommodation
CASE	Contribution to Ariel Spectroscopy of Exoplanets
CASIS	Center for the Advancement of Science in Space
CAST	Center for Applied Space Technology
CBM	Condition-based Maintenance
CCMC	Community Coordinated Modeling Center
CCP	Commercial Crew Program
CCRPP	Civilian Commercialization Readiness Pilot Program
CCRS	Capture, Containment, and Return, System
CCS	Command Control Software
CCSDS	Consultative Committee for Space Data Systems
CDA	Coordinated Data Analysis
CDFF	Commercial Destinations Free Flyers
CDISS	Commercial Destination for International Space Station
CDM	Continuous Diagnostics and Mitigation
CDR	Critical Design Review
CECR	Construction and Environmental Compliance and Restoration
CERCLA	Comprehensive Environmental Response, Compensation, Liability Act
CERES	Clouds and Earth’s Radiant Energy System

ACRONYMS AND ABBREVIATIONS

CERTAIN	City Environment Range Testing for Autonomous Integrated Navigation
CESAS	Committee on Earth Science, and Applications from Space
CESD	Common Exploration Systems Development
CESO	Center Engineering, Safety, and Operations
CFD	Computational Fluid Dynamics
CFM	Cryogenic Fluid Management
CFO	Chief Financial Officer
CFR	Code of Federal Regulations
CFT	Crewed Flight Test
CGE	Concur Government Edition
CHAPEA	Crew Health and Performance Exploration Analog
CHIME	Copernicus Hyperspectral Imaging Mission for the Environment
CHP	Crew Health and Performance
CHS	Crew Health and Safety
CIBER	Cosmic Infrared Background ExpeRiment
CIF	Center Innovation Fund
CIMR	Copernicus Imaging Microwave Radiometer
CIPP	Capital Investment Program Plan
CIR	Critical Integration Review
CIS	Commercial Services, Innovation, and Synergies
CLPS	Commercial Lunar Payload Services
CLV	Commercial Launch Vehicle
CM	Crew Module
CMA	Crew Module Adapter
CMD	Charge Management Device
CME	Coronal Mass Ejections
CMIP	Climate Model Intercomparison Project
CMOS	Complementary-Metal-Oxide Semiconductor
CMP	Contamination Monitoring Package
CMR	Common Metadata Repository
CMV	Co-Manifested Vehicle
CNES	Centre National D'Etudes' Spatiales (French Space Agency)
CO2	Carbon Dioxide
COMSEC	Continuity of Operations, Fire Services, National Security, Communications Security
CONNECTS	Connecting our NASA Network of Educators Collaborating in STEM
COR	Cosmic Origins
COSGC	Colorado Space Grant Consortium
COSI	Compton Spectrometer and Imager
COTS	Commercial Orbital Transportation System
COWVR	Compact Ocean Wind Vector Radiometer

ACRONYMS AND ABBREVIATIONS

CP	Communications Program
CPC	Circumpolar Cyclones
CPF	CLARREO Pathfinder
CRISM	Compact Reconnaissance Imaging Spectrometer for Mars
CRISTAL	Copernicus Polar Ice and Snow Topography Altimeter
CRP	Constant Rate Production
CRREL	Cold Region Research and Engineering Labs
CRS	Commercial Resupply Services
CSA	Canadian Space Agency
CSDA	Commercial SmallSat Data Acquisition
CSESP	Citizen Science for Earth Systems Program
CSLI	CubeSat Launch Initiative
CSM	Crew and Service Module
CSP	Communications Services Program
CSSP	Committee for Solar and Space Physics
CST	Commercial Supersonic Technology
CTIM	Compact Total Irradiance Monitor
CTX	Context Camera
CUI	Controlled Unclassified Information
CURIE	CUbesat Radio Interferometry Experiment
CUSPP	CubeSat mission to Understand Solar Particles over Earth's Poles
CUTE	Colorado Ultraviolet Transit Experiment
CUVIS	Compact Ultraviolet to Visible Imaging Spectrometer
CYGNSS	Cyclone Global Navigation Satellite System
DAA	Deputy Associate Administrator
DAAC	Distributed Active Archive Center
DAEP	DSN Aperture Enhancement Project
DALI	Development and Advancement of Lunar Instrumentation
DARPA	Defense Advanced Research Projects Agency's
DART	Double Asteroid Redirection Test
DAS	Data Acquisition System
DAVINCI	Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging
DAWN	Doppler Aerosol WiNd Lidar Instrument
DCCS	Dream Chaser Cargo System
DCOTSS	Dynamics and Chemistry of the Summer Stratosphere
DCR	Design Certification Review
DDAP	Discovery Data Analysis Program
DDT&E	Design and Development, Test and Evaluation
DEAP	Deep Space Network Aperture Enhancement
DEIA	Diversity, Equity, Inclusion, and Accessibility

ACRONYMS AND ABBREVIATIONS

DEUCE	Dual-channel Extreme Ultraviolet Continuum Experiment
DFO	Designated Federal Official
DHLS	Dynetics Human Landing System
DHS	Department of Homeland Security
DLC	Descent Landing Computer
DLEU	DSN Lunar Exploration Upgrades
DLR	German Aerospace Center
DNA	Deoxy-Ribonucleic Acid
DoD	Department of Defense
DOE	Department of Energy
DOI	Department of Interior
DOJ	Department of Justice
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
DPR	Dual-frequency Precipitation Radar
DRACO	Demonstration Rocket for Agile Cislunar Operations
DRIVE	Diversify, Realize, Integrate, Venture, Educate
DRPS	Dynamic Radioisotope Power System
DSA	Distributed Spacecraft Autonomy
DSAC	Deep Space Atomic Clock
DSCOVR	Deep Space Climate Observatory
DSE	Data System Evolution
DSI	Decadal Survey Incubation
DSL	Deep Space Logistics
DSN	Deep Space Network
DSOC	Deep Space Optical Communications
DSS	Deep Space Station
DTE	Direct-to-Earth
DTN	Delay Tolerant Network
DVT	Design Verification Testing
EAP	Electrified Aircraft Propulsion
EAR	Export Administration Regulations
EATCS	External Active Thermal Control Systems
EC	Exploration Capabilities
ECCO	Estimating Circulation and Climate of the Ocean
ECI	Early Career Innovation
ECLSS	Environmental Control and Life Support System
ECM	Europa Clipper Magnetometer
ECOSTRESS	Ecosystem Spaceborne Thermal Radiometer Experiment on Space Station
ECR	Environmental Compliance and Restoration
ECS	Environmental Control System

ACRONYMS AND ABBREVIATIONS

EDL	Entry, Descent, and Landing
EDP	Enterprise Data Platform
EDS	Electrodynamic Dust Shield
EEE	Electrical, Electronic, and Electro-mechanical
EELV	Evolved Expendable Launch Vehicle
EES	Emergency Egress System
EEV	Earth Entry Vehicle
EGS	Exploration Ground Systems
EHRI	Enterprise HR Integration
EICC	EPSCoR Interagency Coordinating Committee
EIK	Extended Interaction Klystrons
EIR	Enterprise Integration Review
EIS	Europa Imaging System
ELVIS	Expendable Launch Vehicle Integrated Support
EM	Exploration Mission
EMD	Exploration Systems Mission Directorate
EMIT	Earth Surface Mineral Dust Source Investigation
EMS	Environmental Management System
EONS	Engagement Opportunities in NASA STEM
EOS	Earth Observing System
EOSDIS	Earth Observing System Data and Information System
EPA	Environmental Protection Agency
EPACS	Enterprise Physical Access Control System
EPFD	Electrified Powertrain Flight Demonstrations
EPIC	Earth Poly-Chromatic Imaging Camera
ERB	Earth Radiation Budget
ERBS	Earth Radiation Budget Science
ERD	Exploration Research and Development
ERDC	Engineer Research and Development Center
ERO	Earth Return Orbiter
ERP	Expert Review Panel
ESA	European Space Agency
ESCAPADE	Escape and Plasma Acceleration and Dynamics Explorers
ESD	Exploration Systems Development
ESDIS	Earth Science Data and Information System
ESDMD	Exploration Systems Development Mission Directorate
ESDS	Earth Science Data Systems
ESI	Early Stage Innovations
ESM	European Service Module
ESO	Engineering, Safety, and Operations

ACRONYMS AND ABBREVIATIONS

ESPA	ELV Secondary Payload Adapter
ESPRIT	European Systems Providing Refueling, Infrastructure, and Telecommunications
ESSP	Earth System Science Pathfinder
ESTO	Earth Science Technology Office
ETA	Engineering Technical Authority
ETS2	Electronic Government Travel System 2
EUL	Enhanced Use Leasing
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
EUNIS	Extreme Ultraviolet Normal-Incidence Spectrograph
EUS	Exploration Upper Stage
EUV	Extreme-UV
EUVST	Extreme Ultraviolet High-Throughput Spectroscopic Telescope
EVA	Extra-Vehicular Activities
EVC	Earth Venture Continuity
EVI	Earth Venture Instruments
EVM	Earth Venture Missions
EVS	Earth Venture Suborbital
EVZI	Emulsified Zero-Valent Iron
EWC	External Wireless Communication
EXCOM	Executive Committee
EZIE	Electrojet Zeeman Imaging Explorer
FAA	Federal Aviation Administration
FAR	Federal Acquisition Regulation
FAST	Fellows Advancing in Science and Technology
FBCE	Flow Boiling and Condensation Experiment
FDA	Food and Drug Administration
FDC	Flight Demonstrations and Capabilities
FDMS	Federal Docket Management System
FFATA	Federal Funding Accountability and Transparency Act
FFRDC	Federally-Funded Research and Development Center
FGDC	Federal Geographic Data Committee
FIPS	Fast-Imaging Plasma Spectrometer
FIR	Fluids Integrated Rack
FIRST	For the Inspiration and Recognition of Science and Technology
FISMA	Federal Information Security Management Act
FO	Flight Opportunities
FOD	Flight Operations Directorate
FOP	Flight Opportunities Program
FPKI	Federal Public Key Infrastructure
FRR	Flight Readiness Review

ACRONYMS AND ABBREVIATIONS

FSF	Future Systems Formulation
FSP	Fission Surface Power
FSR	Formulation Synchronization Review
FSS	Farside Seismic Suite
FTE	Full-Time Equivalent
FTIS	Flight Test Instrumentation System
GAO	Government Accountability Office
GBM	Gamma-Ray Burst Monitor
GCD	Game Changing Development
GDC	Geospace Dynamics Constellation
GDSCC	Goldstone Deep Space Communications Complex
GE	General Electic
GEDI	Global Ecosystem Dynamics Investigation
GEER	Glenn Extreme Environment Rig
GEL	Growth and Extinction Limit
GEO	Group on Earth Observations
GeoCarb	Geostationary Carbon Observatory
GEOLAB	Geometry Laboratory
GERS	Gateway External Robotics Systems
GETS	Groundwater Extraction and Treatment System
GFE	Government Furnished Equipment
GFZ	German Research Centre for Geosciences
GHG	Greenhouse Gas
GIBS	Global Imagery Browse Services
GISS	Goddard Institute for Space Studies
GLIDE	Global Lyman-alpha Imagers of the Dynamic Exosphere
GLIMR	Geosynchronous Littoral Imaging and Monitoring Radiometer
GLOBE	Global Learning and Observations to Benefit the Environment
GLS	Gateway Logistics Services
GMI	GPM Microwave Imager
GNC	Guidance, Navigation, and Control
GNSS	Global Navigation Satellite System
GO	Guest Observers
GOLD	Global-scale Observations of the Limb and Disk
GONG	Ground Oscillation Network Group
GPHS	General Purpose Heat Source
GPM	Global Precipitation Measurement
GPRAMA	Government Performance and Results Modernization Act
GPS	Global Positioning System
GPSP	Global Positioning System-Payload

ACRONYMS AND ABBREVIATIONS

GRB	Gamma-Ray Bursts
GRC	Glenn Research Center
GS	General Schedule
GSA	Government Services Administration
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
GSI	Ground Systems Implementation
GSLV	Geosynchronous Satellite Launch Vehicle
GSSR	Goldstone Solar System Radar
GST	Global Stocktake’
GT	Ground Terminal
GUSTO	Galactic UltraLong-Duration Balloon Spectroscopic Terahertz Observatory
GW	Gravity Waves
HALO	Habitation and Logistics Outpost
HASP	High Altitude Student Platform
HBCU	Historically Black Colleges and Universities
HCIT	Human Capital Information Technology
HDL	Hazard Detection LIDAR
HEASARC	High Energy Astrophysics Science Archive Center
HECC	High End Computing Capability
HEOMD	Human Exploration and Operations Mission Directorate
HERA	Hybrid Electronic Radiation Assessor
HERMES	Heliophysics Environmental and Radiation Measurement Experiment Suite
HERO	Human Exploration Research Opportunity
HESS	High Energy Stereoscopic System
HFOS	Heliophysics Flight Opportunities Studies
HGA	High Gain Antenna
HHS	Health and Human Services
HIRAD	Hurricane Imaging Radiometer
HIS	Heavy Ion Sensor
HLCS	HALO Lunar Communications System
HLS	Harmonized Landsat Sentinel
HMTA	Health and Medical Technical Authority
HP3	Heat Flow and Physical Properties Package
HPSC	High Performance Spaceflight Computing
HQ	NASA Headquarters
HR	Human Resources
HRD	Hurricane Research Division
HRF	Human Research Facility
HRP	Human Research Program

ACRONYMS AND ABBREVIATIONS

HSFO	Human Space Flight Operations
HSI	Human Systems Integration
HSM	Human Surface Mobility
HT	Hypersonic Technology
HTV	H-II Transfer Vehicle
HV	High Voltage
I&T	Integration and Testing
I&TC	Infrastructure and Technical Capabilities
I3P	IT Infrastructure Integration Program
IA	Independent Assessment
IAE	Integrated Award Environment
IAS	Integration of Automated Systems
IASP	Integrated Aviation Systems Program
IBC	Interior's Business Center
IBEX	Interstellar Boundary Explorer
ICE	Instrument Control Electronics
ICEMAG	Interior Characterization of Europa Using Magnetometry
ICF	Industrial Crystallization Facility
ICG	International Committee on GNSS
ICON	Ionospheric Connection Explorer
ICPS	Interim Cryogenic Propulsion Stage
IDIQ	Indefinite-Delivery-Indefinite-Quantity
IG	Inspector General
IIP	Instrument Incubator Program
ILV	Integrated Lander Vehicle
IM	Information Management
IMAP	Interstellar Mapping and Acceleration Probe
IMC	International Mission Contributions
IMERG	Integrated Multi-satellite Retrievals for GPM
IMM	Integrated Medical Model
IMPACT	Informing Mission Planning via Analysis of Complex Trade
IMPACTS	Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms
IMPALA	Information Management Platform for Data Analytics and Aggregation
INCUS	Investigation of Convective Updrafts
INL	Idaho National Laboratory
InSAR	Interferometric Synthetic Aperture Radar
IOAG	Interagency Operations Advisory Group
IOC	Initial Operational Capabilities
ION	Interplanetary Overlay Network

ACRONYMS AND ABBREVIATIONS

IPAC	Infrared Processing and Analysis Center
IPCC	Intergovernmental Panel on Climate Change
IPWG	International Precipitation Working Group
IRAC	Interdepartment Radio Advisory Committee
IRAD	Independent Research and Development
IRB	Independent Review Board
IRIS	Interface Region Imaging Spectrograph
IROSA	ISS Roll Out Solar Arrays
IRSA	Infrared Science Archive
IRT	Independent Review Team
IRTF	Infrared Telescope Facility
ISA	Israel Space Agency
ISAAC	Integrated System for Autonomous and Adaptive Caretaking
ISD	Interstellar Dust
ISEP	Integrated Solar Energetic Proton
ISM	In-Space Manufacturing
ISO5	International Standards Organization 5
ISPF	In-Space Propulsion Facility
ISRO	Indian Space Research Organization
ISRU	In-Situ Resource Utilization
ISS	International Space Station
ISSAC	International Space Station Advisory Council
ISSNL	ISS National Laboratory
IT	Information Technology
ITAR	International Traffic in Arms
ITL	Integrated Test Lab
ITM	Ionosphere/Thermosphere/Mesosphere
ITP	Integrated Test Platform
IV&V	Independent Verification and Validation
IXPE	Imaging X-ray Polarimetry Explorer
JANUS	Joint Advanced Propulsion Institute
JAXA	Japanese Aerospace Exploration Agency
JCL	Joint Confidence Level
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System
JRC	Joint Research Centre
JSC	Johnson Space Center
JSL	Joint Station Lan
JUICE	Jupiter Icy Moons Explorer
KARI	Korea Aerospace Research Institute

ACRONYMS AND ABBREVIATIONS

KASI	Korea Astronomy and Space Science Institute
KBO	Kuiper Belt Object
KDP	Key Decision Point
KOA	Keck Observatory Archive
KPLO	Korea Pathfinder Lunar Orbiter
KSC	Kennedy Space Center
L1	Lagrangian Point 1
LAN	Local Area Network
LANCE	Land, Atmosphere Near real-time Capability for EOS
LANL	Los Alamos National Laboratory
LaRC	Langley Research Center
LAS	Launch Abort System
LASP	Laboratory for Atmospheric and Space Physics
LBFD	Low Boom Flight Demonstrator
LBNP	Lower Body Negative Pressure
LCC	Launch Control Center
LCPSO	Land Cover Project Science Office
LCRD	Laser Communications Relay Demonstration
LDEP	Lunar Discovery and Exploration Program
LEGS	Lunar Exploration Ground System
LEO	Low-Earth Orbit
LEOS	Legal Enterprise Operating System
LETS	Lunar Exploration Transportation Services
LH2	Liquid Hydrogen
LIGO	Laser Interferometer Gravitational-wave Observatory
LIS	Lightning Imaging Sensor
LISA	Laser Interferometer Space Antenna
LISM	Local Interstellar Medium
LLISSE	Long-Lived In-Situ Solar System Explorer
LMOC	LCRD Mission Operations Center
LOFTID	Low-Earth Orbit Flight Test of Inflatable Decelerator
LRA	Laser Retro-reflector Assembly
LRD	Launch Readiness Date
LRO	Lunar Reconnaissance Orbiter
LSIC	Lunar Surface Innovation Consortium
LSII	Lunar Surface Innovation Initiative
LSITP	Lunar Surface Instrument and Technology Payloads
LSP	Launch Services Program
LTV	Lunar Terrain Vehicle
LVSA	Launch Vehicle Stage Adapter

ACRONYMS AND ABBREVIATIONS

LWIR	Long-Wavelength IR
LWS	Living With a Star
M&IO	Mission Integration and Operations
M&MA	Moon and Mars Architecture
MAA	MUREP Aerospace Academy
MAF	Michoud Assembly Facility
MAGIC	MAGnetometers for Innovation and Capability
MAIA	Multi-Angle Imager for Aerosols
MAIANSE	MUREP for American Indian and Alaska Native STEM Engagement
MARCI	Mars Color Imager
MARSIS	Mars Advanced Radar for Subsurface and Ionospheric Sounding
MASPEX	MAss SPectrometer for Planetary EXploration/Europa
MATA	Motor Adapter Truss Assembly
MAV	Mars Ascent Vehicle
MAVEN	Mars Atmosphere and Volatile EvolutioN
MCD	Mars Campaign Development
MCL	Metrology and Calibration Laboratory
MCR	Mission Concept Review
MCS	Mars Climate Sounder
MDA	MacDonald, Dettwiler and Associates Inc
MDAO	Multi-disciplinary Design, Analyses, and Optimization
MDI	Michelson Doppler Imager
MDR	Mission Definition Review
MDSCC	Madrid Deep Space Communications Complex
MEB	Main Electronics Box
MEDA	Mars Environmental Dynamics Analyzer
MEGA	Mars-Earth Gravity Assist
MEGANE	Mars-moon Exploration with Gamma rays and Neutrons
MEMS	Microelectromechanical Systems
MES	Mission Enabling Services
MEVV	Multi-Element Verification & Validation
MICS	Modern & Inclusive Collaboration Spaces
MIDEX	Medium-Class Explorer
MIE	Museum and Informal Education
MIO	Maturation and Integration Office
MIR	Mission Integration Review
MIRO	MUREP Institutional Research Opportunity
MISE	Mapping Imaging Spectrometer for Europa
MIT	Massachusetts Institute of Technology
ML	Mobile Launcher

ACRONYMS AND ABBREVIATIONS

MLS	Microwave Limb Sounder
MMPACT	Moon-to-Mars Planetary Autonomous Construction Technology
MMRTG	Multi-Mission Radioisotope Thermoelectric Generator
MMS	Magnetospheric Multiscale
MMX	Martian Moons eXploration
MO	Missions of Opportunity
MO&I	Mission Operations and Integration
MODIS	Moderate-Resolution Imaging Spectroradiometer
MOMA	Mars Organic Molecule Analyzer
MOU	Multiple bilateral Memoranda of Understanding
MOXIE	Mars Oxygen In-Situ Resource Utilization Experiment
MPIA	Max Planck Institute for Astronomy
MPL	Micro-Pulse Lidar
MPPF	Multi-Payload Processing Facility
MRO	Mars Reconnaissance Orbiter
MSD	Mission Support Directorate
MSFC	Marshall Space Flight Center
MSI	Minority Serving Institutions
MSL	Mars Science Laboratory
MSR	Mars Sample Return
MSRDC	MSI STEM Research & Development Consortium
MSRR	Materials Science Research Rack
MUREP	Minority University Research and Education Project
MUSE	Multi-slit Solar Explorer
MUSS	Multi-User Systems Support
MW	Megawatt
NAC	NASA Advisory Council
NAIF	Navigation Ancillary Information Facility
NAME	Numerical Atmospheric-dispersion Modelling Environment
NAMIS	NASA Aircraft Management Information System
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASCOM	NASA Communications
NASEM	National Academies of Sciences, Engineering, and Medicine
NASS	National Agriculture Statistics Service
NAVO	NASA Astronomical Virtual Observatories
NCAS	NASA Community College Aerospace Scholars
NCATS	National Center for Advancing Translational Sciences
NCCIPS	National Center for Critical Information Processing and Storage
NCRP	National Council on Radiation Protection

ACRONYMS AND ABBREVIATIONS

NDL	Navigation Doppler Light Detection and Ranging
NDMC	National Drought Mitigation Center
NDSRC	Navy Department of Defense Supercomputing Resource Center
NEA	Near Earth Asteroid
NEAR	Near Earth Asteroid Rendezvous
NEAT	NASA Electric Aircraft Testbed
NED	NASA Extragalactic Database
NEK	Nezemnyy Eksperimental'nyy Kompleks
NEO	Near Earth Object
NEOO	Near-Earth Object Observations
NEOWISE	Near Earth Object Wide-field Infrared Surveyor Explorer
NEPA	National Environmental Protection Act
NESC	NASA Engineering and Safety Center
NET	No Earlier Than
NEXT	NASA Evolutionary Xenon Thruster
NG	Northrop Grumman
NGIS	Northrop Grumman Innovation Systems
NGO	Non-Government Organization
NGS	Northrop Grumman Space
NGSC	Northrop Grumman Systems Corporation
NGSS	Next Generation Science Standards
NHPA	National Historic Preservation Act
NIAC	NASA Innovative Advanced Concepts
NIAID	National Institute of Allergy and Infectious Diseases
NICER	Neutron Star Interior Composition Explorer
NICS	NASA Integrated Communications Services
NIH	National Institutes of Health
NIR	Near Infrared
NIRCam	Near-Infrared Camera
NIRPS	National Institutes for Rocket Propulsion Systems
NIRVSS	Near InfraRed Volatiles Spectrometer System
NISAR	NASA-ISRO Synthetic Aperture Radar
NIST	National Institute of Standards and Technology
NISTAR	National Institute of Standards and Technology Advanced Radiometer
NLS	NASA Launch Services
NO2	Nitrogen Dioxide
NOAA	National Oceanic and Atmospheric Administration
NOFO	Notice of Funding Opportunity
NOMAD	Nadir and Occultation for MArs Discovery
NORR	Normal Operations Readiness Review

ACRONYMS AND ABBREVIATIONS

NOS	New Observing Strategies
NPLP	NASA Provided Lunar Payloads
NPR	NASA Procedural Requirements
NPS	National Park Service
NRA	NASA Research Announcement
NRESS	National Research and Educational Support Services
NRHO	Near Rectilinear Halo Orbit
NRPTG	National Rocket Propulsion Test Group
NSBE	National Society of Black Engineers
NSC	NASA Safety Center
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
NSN	Near Space Network
NSPIRES	NASA Solicitation and Proposal Integrated Review and Evaluation System
NSPM	National Security Presidential Memorandum
NSS	Neutron Spectrometer System
NSSC	NASA Shared Services Center
NSTGRO	NASA Space Technology Graduate Research Opportunities
NTF	National Transonic Facility
NTIA	National Telecommunications and Information Administration
NTTS	NASA's Technology Transfer System
NuSTAR	Nuclear Spectroscopic Telescope Array
O&C	Operations and Checkout
O&M	Operations and Maintenance
O&TM	Operations and Test Management
O2OGS	Orion Artemis-II Optical Ground Segment
OA	Office of Audits
OCE	OSMA, and the Chief Engineer
OCFO	Office of the Chief Financial Officer
OCHCO	Office of Chief Human Capital Officer
OCHMO	Office of Chief Health and Medical Officer
OCI	Ocean Color Instrument
OCIO	Office of the Chief Information Officer
OCO	Orbiting Carbon Observatory
OCOMM	Office of Communications
OCSS	Orion Crew Survival System Suit
OCT	Office of the Chief Technologist
ODEO	Office of Diversity and Equal Opportunity
ODNI	Office of the Director of National Intelligence
OEPM	Office of Education Performance Measurement

ACRONYMS AND ABBREVIATIONS

OFT	Orbital Flight Test
OGA	Oxygen Generation Assembly
OGC	Office of the General Counsel
OGS	Oxygen Generator System
OI	Office of Investigations
OIG	Office of Inspector General
OIIR	Office of International and Interagency Relations
OLIA	Office of Legislative and Intergovernmental Affairs
OLIF	Orion Life Support Integration Facility
OMB	Office of Management and Budget
OMDS	Oxygen Deficiency Monitoring System
OME	Orion Main Engine
OMI	Ozone Monitoring Instrument
OMP	Office of Management and Planning
OMPS	Ozone Mapping and Profiler Suite
OPM	Office of Personnel Management
OPOC	Orion Production and Operations Contract
OPS	Office of Protective Services
ORNL	Oak Ridge National Laboratory
ORR	Operational Readiness Review
OSA	Orion Stage Adaptor
OSAM	On-orbit Servicing, Assembly, and Manufacturing
OSBP	Office of Small Business Programs
OSHA	Occupational Safety and Health Administration
OSMA	Office of Safety and Mission Assurance
OSS	Open Source Software
OSST	Ocean Salinity Science Team
OSTEM	Office of STEM Engagement
OSTM	Ocean Surface Topography Mission
OSTST	Ocean Surface Topography Science Team
OU	University of Oklahoma
PAC	Planetary Science Advisory Committee
PACE	Payload Accelerator for CubeSat Endeavors
PAM	Private Astronaut Mission
PASS	Precision Assembled Space Structure
PBL	Planetary Boundary Layer
PBPS	Post Boost Propulsion System
PCA	Physicians' Comparability Allowance
PCI	Project Controls Integration
PCM	Post Certification Mission

ACRONYMS AND ABBREVIATIONS

PCOS	Physics of the Cosmos
PDCO	Planetary Defense Coordination Office
PDP	Plasma Diagnostics Package
PDR	Preliminary Design Review
PDS	Planetary Data System
PEAR	Payload Enclosed Access Room
PFAS	Polyfluoroalkyl Substances
PGS	Pressure Garment Subsystem
PI	Principal Investigator
PIC	Photonic Integrated Circuit
PICASSO	Planetary Instrument Concepts for the Advancement of Solar System Observations
PIMS	Plasma Instrument for Magnetic Sounding
PIR	Program Implementation Review
PIV	Personal Identity Verification
PLSS	Portable Life Support Subsystem
PMA	Pressurized Mating Adapter
PMPO	Planetary Missions Program Office
PMSR	Project Mission System Review
PMT	Program Management Team
PNT	Positioning, Navigation, and Timing
POWER	Prediction of Worldwide Energy Resources
PPE	Power and Propulsion Element
PPF	Payload Processing Facility
PPP	Paycheck Protection Program
PRAC	Pandemic Response Accountability Committee
PREFIRE	Polar Radiant Energy in the Far Infrared Experiment
PRIME	Polar Resources Ice Mining Experiment
PRISM	Payloads and Research Investigations on the Surface of the Moon
PSD	Planetary Science Division
PSI	Physical Sciences Information System
PSM	Procurement Strategy Meeting
PSP	Parker Solar Probe
PSR	Pre-Ship Review
PSRE	Propulsion System Rocket Engine
PTD	Pathfinder Technology Demonstrator
PTS	Propellant Transfer Subsystem
PUEO	Payload for Ultrahigh Energy Observation
PUI	Primarily Undergraduate Institutions
PUNCH	Polarimeter to Unify the Corona and Heliosphere
PWS	Plasma Wave Science

ACRONYMS AND ABBREVIATIONS

QETS	Quiet Engine Test Stand
QSAR	Qualification System Acceptance Review
R&A	Research and Analysis
R&D	Research and Development
R3	Rapid Response Research
RAAMBO	Refractory Alloy Additive Manufacturing Build Optimization
RAD	Radiation Assessment Detector
RAM	Revolutionary Aviation Mobility
RAMPT	Rapid Analysis Manufacturing Propulsion Technology
RAP	Robotics Alliance Project
RBI	Radiation Budget Instrument
RBVM	Radiator Beam Valve Module
RCRA	Resource Conservation and Recovery Act
RDAP	Rosetta Data Analysis Program
REASON	Radar for Europa Assessment and Sounding: Ocean to Near-surface
RF	Radio Frequency
RFI	Request for Information
RFP	Request For Proposal
RFU	Radio-Frequency Unit
RHU	Radioisotope Heater Unit
RID	Research Infrastructure Development
RIME	Radar for Icy Moons Exploration
RISE	Rotation and Interior Structure Experiment
RMO	Resource Management Office
ROI	Research Operations and Integration
ROSA	Roll Out Solar Array
ROSES	Research Opportunities in Space and Earth Sciences
RPA	Robotic Process Automation
RPOD	Rendezvous, Proximity Operations and Docking
RPS	Radioisotope Power Systems
RPSF	Rotation, Processing, and Surge Facility
RPT	Rocket Propulsion Test
RRAC	Regulatory Risk Analysis and Communication
RRP	Redwire Regolith Print
RSB	Research Support Building
RSD	Ring-Sheared Drop
RSL	Recurring Slope Lineae
RTA	Robotic Transfer Arm
RV	Radial Velocity
RVLT	Revolutionary Vertical Lift Technology

ACRONYMS AND ABBREVIATIONS

S&MA	Safety and Mission Assurance
SAC	Super-lightweight Aerospace Composites
SAF	Sustainable Aviation Fuel
SAGE	Stratospheric Aerosol and Gas Experiment
SALI	Space Automated Laboratory Incubator
SALMON	Stand Alone Missions of Opportunity
SAM	Spacecraft Atmosphere Monitor
SANS	Spaceflight Associated Neuro-ocular Syndrome
SAR	Synthetic Aperture Radar
SARP	Student Airborne Research Program
SASSIE	Salinity and Stratification at the Sea Ice Edge
SAT	Strategic Astrophysics Technology
SATCOM	Satellite Communications
SATERN	System for Administration, Training, and Educational Resources at NASA
SBA	Small Business Administration
SBG	Surface Biology and Geology
SBIR	Small Business Innovation Research
SC	Scientific Computing
SCA	Sensor Chip Assembly
SCALPSS	Stereo Camera for Lunar Plume Surface Studies
SCCS	Spacecraft Command and Control System
SCOR	Spacecraft Oxygen Recovery
SDAC	Solar Data Center
SDL	Space Dynamics Laboratory
SDO	Solar Dynamics Observatory
SDR	Single Design Review
SDS	Survey Data System
SDTS	Six-Degree-of-Freedom Test System
SE&I	Systems Engineering and Integration
SEIS	Seismic Experiment for Interior Structure
SEM	Scanning Electron Microscope
SEP	Solar Electric Propulsion
SERFE	Spacesuit Evaporation Rejection Flight Experiment
SEWP	Solutions for Enterprise-Wide Procurement
SFCO	Space Flight Crew Operations
SFD	Sustainable Flight Demonstrator
SFNP	Sustainable Flight National Partnership
SFO	Suborbital Flight Opportunities
SFR	Sample Fetch Rover
SFS	Space and Flight Support

ACRONYMS AND ABBREVIATIONS

SG	Space Grant
SGP	Space Geodesy Project
SGSS	Space Network Ground Segment Sustainment
SGTRC	Space to Ground Transmitter Receiver Controller
SHIELDS	Spatial Heterodyne Interferometric Emission Line Dynamics Spectrometer
SHREC	The Supplemental Heat Evaporative Cooler
SICA	Central American Integration System
SIF	Solar-Induced Fluorescence
SIM	Spectral Irradiance Monitor
SIPS	Science Investigator-led Processing Systems
SIR	System Integration Review
SIRIUS	Scientific International Research in Unique Terrestrial Station
SLI	Sustainable Land Imaging
SLR	Satellite Laser Ranging
SLS	Space Launch System
SM	Service Module
SMA	Safety and Mission Assurance
SMAP	Soil Moisture Active Passive
SMD	Science Mission Directorate
SMEX	Small Explorers
SMOS	Soil Moisture and Ocean Salinity
SNC	Sierra Nevada Corp
SNWG	Satellite Needs Working Group
SO2	Sulfur Dioxide
SOC	Solar Orbiter Collaboration
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOFIE	Solar Occultation For Ice Experiment
SOHO	Solar and Heliospheric Observatory
SOMA	Science Office for Mission Assessments
SOMD	Space Operations Mission Directorate
SPARX	Sparking Participation in Authentic Real-world eXperiences
SPDA	Space Physics Data Archive
SPDF	Space Physics Data Facility
SPEC	Stages Production and Evolution Contract
SPIDER	SPace Infrastructure DExterous Robot
SPIE	Spacecraft Payload Integration and Evolution
SPLICE	Safe and Precise Landing – Integrated Capabilities Evolution
SPOCS	Student Payload Opportunity with Citizen Science
SPR	Surface Pressurized Rover
SPRITE	Supernova Remnants and Proxies for ReIonization Testbed Experiment

ACRONYMS AND ABBREVIATIONS

SRAG	Space Radiation Analysis Group
SRB	Standing Review Board
SRD	Service Requirements Document
SRON	Netherlands Institute for Space Research
SRR	Systems Requirements Review
SRT	Senior Review Team
SRTMV	Solid Rocket Test Motor Vehicle
SSC	Stennis Space Center
SSFL	Santa Susana Field Lab
SSI	Spectral Solar Irradiance
SSMO	Space Science Mission Operations
SSMS	Safety, Security, and Mission Services
SST	Small Spacecraft Technology
SSV	Space Service Volume
SSW	Solar Systems Workings
STA	Structural Test Article
STAR	Strategic Technology Architecture Roundtable
STDT	Science and Technology Definition Team
STEM	Science, Technology, Engineering, and Mathematics
STEREO	Solar Terrestrial Relations Observatory
STGT	Second TDRS Ground Terminal
STI	Scientific and Technical Information
STICS	SupraThermal Ion Composition Spectrometer
STIGUR	Space Technology Industry-Government-University Roundtable
STMD	Space Technology Mission Directorate
STP	Solar Terrestrial Probes
STRG	Space Technology Research Grants
STRI	Space Technology Research Institutes
STROFIO	Start from a ROtating FIeld mass spectrOmeter
STS	Sample Transfer System
STTR	Small Business Technology Transfer
SUDA	SUrface Dust Analyzer
SUSG	Space Use SubGroup
SWAN	Solar Wind ANisotropies
SWAPI	Solar Wind and Pickup Ions
SWARC	Space Weather Applied Research Challenges
SWIM	Subsurface Water Ice Mapping
SWMU	Solid Waste Management Unit
SWO2R	Space Weather Operations to Research
SWOT	Surface Water and Ocean Topography

ACRONYMS AND ABBREVIATIONS

SWS	System-Wide Safety
T2	Technology Transfer
T2X	Technology Transfer Expansion
TA	Technical Authority
TACP	Transformative Aeronautics Concepts Program
TAGSAM	Touch and Go Sample Acquisition Mechanism
TALOS	Thruster Advancement for Low-temperature Operation in Space
TAMD	Technology Analysis and Mission Design
TAPR	Technical Assessment Periodic Review
TASI	Thales Alenia Space Italia
TBCC	Turbine-Based Combined Cycle
TBIRD	TeraByte InfraRed Delivery
TCAN	Theoretical and Computational Astrophysics Network
TCCON	Total Carbon Column Observing Network
TDM	Technology Demonstration Missions
TDO	Technology Demonstration Opportunity
TDRR	Technical Data Requirements and Reporting
TDRS	Tracking and Data Relay Satellites
TDT	Transonic Dynamics Tunnel
TEC	Total Electron Content
TEMPO	Tropospheric Emissions: Monitoring of Pollution
TESS	Transiting Exoplanet Survey Satellite
TGO	Trace Gas Orbiter
THEMIS	Time History of Events and Macroscale Interactions during Substorms
TIDES	Thriving In Deep Space
TILE	Tile Ionic Liquid Electrospray
TIM	Total Irradiance Monitor
TIMED	Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics
TLI	Trans-Lunar Injection
TOPEX	Topography Experiment
TOPS	Transform to Open Science
TP	Technology Pathfinder
TPS	Thermal Protection System
TRACERS	Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites
TRIDENT	The Regolith and Ice Drill for Exploring New Terrain
TRISH	Translational Research Institute for Space Health
TRL	Technology Readiness Level
TRMM	Tropical Rainfall Measuring Mission
TRN	Terrain Relative Navigation

ACRONYMS AND ABBREVIATIONS

TROPICS	Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats
TRR	Test Readiness Review
TSC	Telescience Support Center
TSI	Total Solar Irradiance Sensor
TTBW	Transonic Truss-Braced Wing
TTT	Transformational Tools and Technologies
TUI	Tethers Unlimited Inc
TWS	Terrestrial Water Storage
UAG	Users' Advisory Group
UAM	Urban Air Mobility
UAS	Unmanned Aircraft Systems
UAV	Unmanned Ariel Vehicle
UAVSAR	Uninhabited Aerial Vehicle Synthetic Aperture Radar
UEI	Unique Entity Identifier Implementation
UFE	Unallocated Future Expenses
UHF	Ultra-High Frequency
UI	University Innovation
UK	United Kingdom
UKSA	United Kingdom Space Agency
ULA	United Launch Alliance
ULI	University Leadership Initiative
ULS	United Launch Services
ULTRASAT	Ultraviolet Transient Astronomy Satellite
UNCOPUOS	United Nations Committee on the Peaceful Uses of Outer Space
UNESCO	United Nations Educational, Scientific, and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UPA	Urine Processor Assembly
UPCG	Uniform Protein Crystal Growth
UPS	Uninterruptible Power Supplies
UQ	Uncertain Qualification
USA	Universal Stage Adapter
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
USGCRP	United States Global Change Research Program
USGEO	U.S. Group on Earth Observations
USGS	The U.S. Geological Survey
USOS	United States Orbital Segment
USSF	United States Space Force
UTM	UAS Traffic Management

ACRONYMS AND ABBREVIATIONS

UV	Ultraviolet
UVS	Europa Ultraviolet Spectrograph
UWBRAD	Ultra-Wideband Software Defined Microwave Radiometer
UWMS	Universal Waste Management System
VA	Veterans Administration
VAB	Vehicle Assembly Building
VADR	Venture-Class Acquisitions of Dedicated and Rideshare
VALUABLES	Valuation of Applications Benefits Linked to Earth Science
VASI	Venus Atmospheric Structure Investigation
VCLS	Venture Class Launch Services
VEM	Venus Emissivity Mapper
VERITAS	Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy
VIIRS	Visible Infrared Imaging Radiometer Suite
VIPER	Volatiles Investigating Polar Exploration Rover
VIS	Vibration Isolation System
VISAR	Venus Interferometric Synthetic Aperture Radar
VISE	Vehicle Interfaces to Suit Equipment
VISOR	Venus Imaging System for Observational Reconnaissance
VLBI	Very Long Baseline Interferometry
VLF	Very Low Frequency
VLISM	Very Local Interstellar Medium
VMS	Venus Mass Spectrometer
VOI	Venus Orbit Insertion
VPN	Virtual Private Network
VRT	VIPER Review Team
VSAT	Vertical Solar Array Technology
VSFB	Vandenberg Space Force Base
VTLS	Venus Tunable Laser Spectrometer
VTOL	Vertical Takeoff and Landing
WAVES	Radio and Plasma Wave Experiment
WCF	Working Capital Fund
WDR	Wet Dress Rehearsal
WFF	Wallops Flight Facility
WISE	Wide-field Infrared Survey Explorer
WIT	Water Impact Tests
WIYN	Wisconsin-Indiana-Yale-National Optical Astronomy Observatory
WMKO	W.M. Keck Observatory
WOMA	Wide Field Instrument Opto-Mechanical Assembly
WOSB	Woman-owned Small Business
WPA	Water Processor Assembly

ACRONYMS AND ABBREVIATIONS

WSTF	White Sands Test Facility
WWAO	Western Water Applications Office
xEVA	Exploration Extravehicular Activity
XMM	X-ray Multi-Mirror Mission
XQC	X-ray Quantum Calorimeter
XRCF	X-ray Cryogenic Facility
XRISM	X-ray Imaging and Spectroscopy Mission
XVS	Xternal Vision System
YORPD	Yearly Opportunities in Research for Planetary Defense
ZEV	Zero Emission Vehicle
ZTNA	Zero Trust Network Architecture