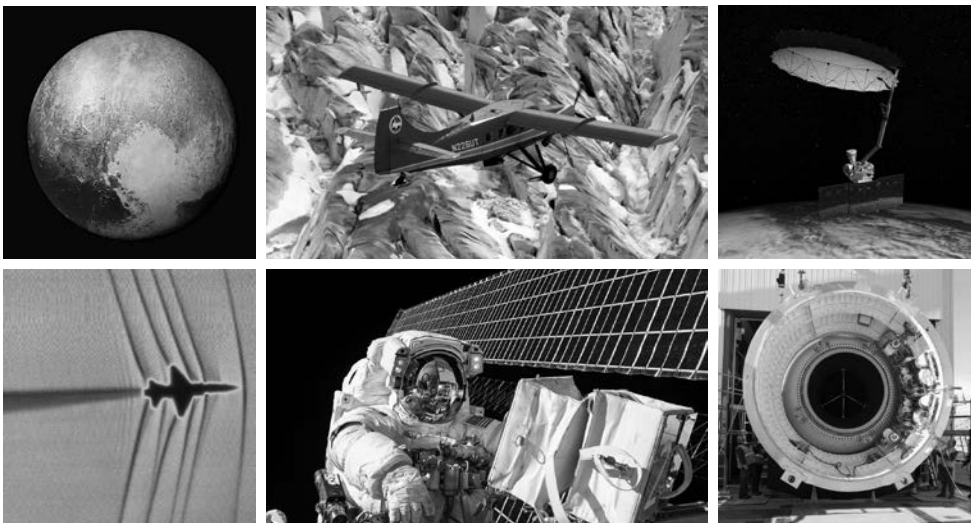
Aeronautics and Space Report of the President

Fiscal Year 2015 Activities



Aeronautics and Space Report
OF THE PRESIDENT

Fiscal Year 2015
Activities

The National Aeronautics and Space Act of 1958 directed the annual Aeronautics and Space Report to include a "comprehensive description of the programmed activities and the accomplishments of all agencies of the United States in the field of aeronautics and space activities during the preceding calendar year." In recent years, the reports have been prepared on a fiscal-year basis, consistent with the budgetary period now used in programs of the Federal Government. This year's report covers activities that took place from October 1, 2014, through September 30, 2015. Please note that these activities reflect the Federal policies of that time and do not include subsequent events or changes in policy.

On the title page, clockwise from the top left: **1.** Pluto is seen from the Long Range Reconnaissance Imager (LORRI) aboard NASA's New Horizons spacecraft, taken on July 13, 2015, when the spacecraft was 476,000 miles (768,000 kilometers) from the surface. Credits: NASA/Applied Physics Laboratory (APL)/Southwest Research Institute (SwRI). **2.** A DHC-3 Otter is flown in NASA's Operation IceBridge-Alaska survey of mountain glaciers in Alaska. Credit: NASA/Chris Larsen, University of Alaska-Fairbanks. **3.** This image shows an artist's concept of NASA's Soil Moisture Active Passive (SMAP) mission. Credit: NASA/Jet Propulsion Laboratory (JPL)–California Institute of Technology. **4.** Engineers at Orbital ATK prepare to test the largest, most powerful booster ever built for NASA's new rocket, the Space Launch System (SLS). Credit: Orbital ATK. **5.** NASA astronaut Scott Kelly works outside the International Space Station (ISS) on the 190th spacewalk in support of ISS assembly and maintenance. Credit: NASA. **6.** This schlieren image of shock waves created by a T-38C in supersonic flight was captured using the sun's edge as a light source and then processed using NASA-developed code. Credit: NASA.

Table of Contents

This page is intentionally left blank.

National Aeronautics and Space Administration

NASA

Human Exploration and Operations Mission Directorate

International Space Station

The International Space Station (ISS) continued its focus on research and technology development in such disciplines as biology, human research, biotechnology, Earth science, physical science, astrophysics, and satellite servicing during FY 2015. Also during FY 2015, Space Exploration Technologies Corporation (SpaceX) completed two commercial cargo missions and Japan's H-II Transfer Vehicle (HTV) completed one cargo mission. NASA continued modifications to docking ports that will allow the ISS to accommodate two docking ports for visiting vehicles, enabling traffic flexibility and port redundancy for U.S. operating segment crew and cargo vehicle missions.

FY 2015 presented one of the ISS Program's toughest logistical challenges. Over the course of eight months, the ISS Program lost three cargo resupply vehicles in launch mishaps: Orbital-ATK's Orbital 3 failed immediately after launch on October 28, 2014; Russia's Progress 59P, just before reaching orbit on April 28, 2015; and SpaceX-7, a few minutes into flight on June 28, 2015. The ISS Program managed to mitigate the impacts; consumables remained in good shape and research was stockpiled on board, waiting to be executed. The ISS Program successfully planned for contingencies, evidenced by the fact that after losing three cargo resupply flights in about eight months, the Station supported six crewmembers

and continued a full research utilization program. The Russian Progress returned to flight in June 2015; Orbital ATK planned to return to flight in December 2015; and SpaceX plans to return to flight in early 2016.

During 2015, NASA continued planning the ISS's extension to at least 2024 to align with the Obama administration's announced intent. The extension allows NASA a decade to help transition low-Earth orbit from exclusive to accessible; offers scientists and engineers the time they need to assure the future of exploration, scientific discoveries, and economic development; and presents important new opportunities to develop the tools needed for future missions to deep space, such as testing essential technologies and hardware related to long-duration journeys.

Expedition 42 crewmembers NASA astronaut Terry Virts, Roscosmos cosmonaut Anton Shkaplerov, and European Space Agency (ESA) astronaut Samantha Cristoforetti joined the Expedition 41 crew on the ISS on November 23, 2014. Crewmembers performed three extravehicular activities (EVAs) to prepare for the arrival and installation of the International Docking Adapters, which will provide additional docking capabilities for visiting vehicles. SpaceX-5 launched on January 10, 2015, delivering 3,700 pounds of pressurized and unpressurized cargo, including research experiments, food, crew provisions, and exercise equipment, plus the Cloud-Aerosol Transport System (CATS) to measure and characterize cloud and aerosol effects to improve climate models.

On March 27, 2015, Expedition 43 crewmembers NASA astronaut Scott Kelly, and Russian cosmonauts Mikhail Kornienko and Gennady Padalka joined the Expedition 42 crew on the ISS. NASA began a one-year, U.S.-Russian joint human health and performance research project with Scott Kelly and Mikhail Kornienko, who will stay aboard the Station for one year. While Kelly lives on board the Station, his identical twin brother, retired NASA astronaut Mark Kelly, is participating in the study on Earth, allowing NASA to better isolate the deleterious effects of spaceflight on the human body and aid in the development of countermeasures for these effects. This research should be invaluable to the preparation for future missions to study the effects of long-duration space missions on the human body. SpaceX-6 launched on April 14, 2015, delivering 4,200 pounds of research experiments, food, crew provisions, and exercise equipment. The cargo included 20 mice for the second Rodent Research investigation to continue the study of

accelerated bone and muscle loss in space, which could lead to new treatments for osteoporosis and muscle wasting on Earth, as well as the Robotic Refueling Mission Phase 2 (RRM-P2) equipment to continue the robotic servicing investigation for satellite servicing.

The loss of Russia's Progress 59P on April 28, 2015, delayed the return of the Expedition 42 crew to Earth for four weeks and the launch of the Expedition 43 crew for eight weeks. The Expedition 42 crew returned to Earth on June 11, 2015, after spending six months on orbit. On June 28, 2015, the SpaceX-7 cargo resupply vehicle failed a few minutes into flight, resulting in the loss of all cargo on board. The Russian Progress returned to flight on July 3, 2015, after a thorough investigation, carrying 1,900 pounds of propellant, oxygen, water, food, and experiment hardware. With this delivery, the ISS had sufficient supplies to last until October 2015.

The Expedition 44 crewmembers—NASA astronaut Kjell Lindgren, Russian cosmonaut Oleg Kononenko, and JAXA astronaut Kimiya Yui—joined the Expedition 43 crew on the ISS on July 22, 2015. The arrival of the three crewmembers returned the Station's crew complement to six. Russian crewmembers conducted a six-hour spacewalk on August 10, 2015, to install new equipment on the Russian segment and conduct a detailed photographic inspection of the exterior of the Station. On August 19, 2015, Japan's HTV-5 launched with 10,000 pounds of cargo and science materials, including critical spares lost on SpaceX-7, as well as the CALorimetric Electron Telescope (CALET), designed to search for dark matter, measure cosmic rays, and observe sources of high-energy phenomena in the galaxy. These crewmembers became the first to harvest and eat crops grown aboard the Station in the Veggie hardware, another necessary advance for astronauts traveling on deep space missions.

Finally, Expedition 45 crewmembers Russian cosmonaut Sergey Volkov, ESA astronaut Andreas Mogensen, and Kazakh cosmonaut Aidyn Aimbetov launched on September 2, 2015, joining Expedition 43 and 44 crew to support ten days of nine crew operations for the first time since 2013. On September 15, 2015, Kelly and Kornienko reached the halfway point of their one-year mission to advance understanding of the medical and psychological challenges astronauts face during long-duration spaceflight.

Launch Services

During FY 2015, the Launch Services Program (LSP) successfully launched two major science missions: the Soil Moisture Active Passive (SMAP) and the Magnetospheric Multiscale (MMS). SMAP launched on January 31, 2015, aboard a Delta II rocket from Vandenberg Air Force Base in California. MMS launched on March 12, 2015, aboard an Atlas V rocket from Cape Canaveral Air Force Station in Florida. The LSP also continued to provide launch-related systems engineering, launch integration, and mission design and analysis support to over 40 NASA-sponsored missions in various phases of development. To learn more about these and other NASA science missions, see the Science Mission Directorate (SMD) section in this report.

The LSP continued its efforts to expand the selection of launch vehicles, working across the launch-vehicle industry to support the continued growth of the U.S. commercial space sector by providing competitive opportunities to U.S. commercial launch providers. In FY 2015, the program acquired launch services for three future science missions: the Ionospheric Connection Explorer (ICON), the Transiting Exoplanet Survey Satellite (TESS), and the Solar Probe Plus (SPP). ICON will launch on Orbital ATK's Pegasus XL from Kwajalein Atoll in the Marshall Islands, followed by TESS on a SpaceX Falcon 9 v1.1 and SPP on United Launch Services' Delta IV Heavy rocket launching from the Cape.

NASA and LSP also partnered with several universities to launch small research satellites through the Educational Launch of Nanosatellites project and the CubeSat Launch Initiative, which provides rideshare opportunities for small-satellite payloads to fly on upcoming launches when space is available. These partnerships provide educational opportunities for students in science, technology, engineering, and mathematics disciplines, thereby strengthening the Nation's future workforce. In addition, as CubeSats continue to play an increasingly larger role at NASA, LSP began work to develop a new Venture Class Launch Service (VCLS) in order to create an alternative to the current rideshare approach and foster a commercial launch market dedicated solely to flying small-satellite payloads. On September 30, 2015, NASA awarded three VCLS contracts to Firefly Space Systems, Inc.; Rocket Lab USA; and Virgin Galactic LLC, with the first

demonstration launch scheduled for summer 2017. To date, CubeSats have been selected from 29 states across the United States, with 43 launched and 14 manifested on NASA, National Reconnaissance Office, U.S. Air Force, and commercial missions. The LSP also completed the certification effort for SpaceX's Falcon 9 v1.1 rocket in May 2015 and certified it as a medium-risk launch vehicle as defined in NASA policy, with a single certification exception. SpaceX is working to correct the issue that caused the exception, and LSP has put the appropriate steps in place to mitigate the technical risk.

Space Communications and Navigation

In FY 2015, the Space Communications and Navigation (SCaN) Program Office remained focused on the critical sustainability and development of the ground and space components of the networks that provide space communications for NASA's missions. The three networks—the Near Earth Network (NEN), the Space Network (SN) Tracking and Data Relay Satellite System (TDRSS), and the Deep Space Network (DSN)—continued to meet the space communications needs, such as Earth monitoring and support of deep space science missions, of a wide range of customers, both internal and external to NASA. SCaN continued to surpass its requirement of 95 percent proficiency in FY 2015, with at least 99 percent proficiency in all of its networks, providing communication and navigation services to all science and human missions.

SCaN completed some key milestones during FY 2015:

- SCaN successfully supported all pre-mission verification testing, the launch, and the mission through splashdown of the Exploration Flight Test–1 (EFT-1) Orion mission on December 5, 2014.
- SCaN successfully completed TDRS-12 Initial Operational Capability (IOC) testing on January 25, 2015, and placed it into service as TDRS-East on February 12, 2015.
- SCaN completed the SN Blossom Point Ground Station, which is providing operational support to customers.
- TDRS-M successfully completed all system and environmental testing and has been placed in storage, pending launch in October 2017.

- The Space Network Ground Segment Sustainment (SGSS) Project successfully completed project rebaseline by completing Critical Design Review (CDR) closeout, termination review, and rebaseline review (updated Key Decision Point–C [KDP-C]).
- The SGSS project completed Increment A4 development and integration, including fleet management and additional signal-processing capabilities.
- The NEN project successfully completed Launch Communications System (LCS) CDR. This accomplishment paved the way for the buildup of the Kennedy Uplink Station (KUS) and Ponce De Leon (PDL) tracking station required for Exploration Mission–1 (EM-1) for Orion and Space Launch System (SLS) early ascent coverage.
- The DSN Aperture Enhancement Project successfully completed its first new 34-meter deep space beam waveguide antenna in Canberra, Australia. The new Deep Space Station–35 is now fully operational and meets the requirements of NASA's missions.
- The DSN complexes at Goldstone, Madrid, and Canberra provided flawless mission support to the critical approach and flyby phases of New Horizons Pluto flyby.
- SCaN replanned the Laser Communication Relay Demonstration (LCRD) due to changes in the available funding in FY 2015 and FY 2016 with a new launch date of June 2019 (a change of six months). The 1.25-gigabit-per-second-data-rate ground modem successfully demonstrated interoperability with the test bed at the Massachusetts Institute of Technology's (MIT) Lincoln Laboratory. The demonstration is a major first step toward commercializing laser communications for near-Earth users and has seen significant response from industry in an FY 2015 open call for Guest Investigators during its full demonstration beginning in 2019.
- The SCaN Testbed (STB) continued operations externally on the ISS and has logged over 2,500 hours of operations since its launch in 2012. In FY 2015, the STB developed several important technologies advancing the future of SCaN networks and has partnered with ten commercial companies, eight universities, and three other Government agencies. The project demonstrated the capability of transmission at a data rate of nearly

1 gigabit per second over that of the Ka-band, winning a NASA Silver Achievement Medal for the team's efforts. Separate work on the Digital Video Broadcast Second Generation transmission from space demonstrated a better downlink to a ground station through improved quality in video reception. Commercial standards derived from the SCaN-developed technologies help future NASA networks be more interoperable, increase network throughput, and enhance spectrum efficiency by allowing greater amounts of data to be transmitted in a given bandwidth and adjusting data rates according to radio-frequency link conditions.

- The Spectrum Management Program continued to work with the White House, Congress, national regulators, and interagency partners in implementing the President's Broadband Initiative.
- The Consultative Committee for Space Data Systems (CCSDS) is a major international organization comprising 11 international space agencies; it develops internationally agreed-upon and interoperable space communications standards that enable joint international missions and reduce cost and risk to space missions. In 2015, SCaN engineers led CCSDS working groups in completing many new standards and took leadership of the new working group chartered to develop new standards for optical communications.
- SCaN continued in its role as the Executive Director of the National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board, an august body of PNT experts from within industry and the international community.

Human Spaceflight Capabilities

By the end of FY 2015, the Rocket Propulsion Test (RPT) Program had safely performed 453 tests. Test time totaled over 116,262 seconds, with more than 10,062 seconds of hot fire at various levels of thrust. During this period, the test facilities had six facility-caused test delays resulting in a 98.7 percent facility readiness, far exceeding the 90 percent RPT Annual Performance Indicator.

In FY 2015, Stennis Space Center (SSC) had several test programs under way, including RS-25 in support of the SLS Program, as well as flight certification testing for the Aerojet Rocketdyne RS-68 engine in support of the United States Air Force (USAF) and United Launch Alliance (ULA). Development testing continued for NASA's Morpheus lander, as well as subscale testing of the SpaceX Raptor engine. Refurbishment and repair activities continued for critical enabling infrastructure, including replacing both the B-leg and the A-leg of the high-pressure industrial water system and restoring the B-2 test stand for SLS core stage testing.

In 2015, following the completion of the J-2X engine in FY 2014, SSC transitioned the SSC A-2 test stand to a mothball status. In January 2015, after the completion of facility modifications and the design and manufacturing of the necessary Special Test Equipment (STE), SSC completed the first test of the SLS RS-25 engine on the SSC A-1 test stand. In addition to the testing in support of the SLS Program, SSC began a test campaign supporting the development of a self-pumping diffuser for the White Sands Test Facility (WSTF) Orion European Service Module test campaign. Other activities at SSC included the buildup of systems in the E-Complex required to support the joint Department of Defense (DOD)–NASA hydrocarbon boost program and the Aerojet Rocketdyne Liquid Oxygen (LOX) and Refined Petroleum (Rp) development program.

Marshall Space Flight Center (MSFC) continued testing engine components manufactured using advanced technologies, including components built using select laser melting. In addition to testing the components manufactured using advanced technologies, MSFC tested articles using LOX, liquid methane (LCH_4), and new LOX Rp combustion techniques.

WSTF continued the buildup and preparation of Test Stand 301 to support 2016 testing of the Orion ESA Service Module (SM) and began construction activities on Test Stand 301A to support the Boeing Company's CST-100 crew abort system and SM testing. In addition to the two SM programs, WSTF also provided test support for Boeing, the Missile Defense Agency (MDA), the USAF Minuteman, and the USAF Peacekeeper demilitarization.

Glenn Research Center's (GRC) Plum Brook Station (PBS) collaborated with an Agency high-altitude balloon program to perform a long-duration thermal vacuum test on a payload package during a standard facility Integrated Systems Test (IST).

The test ran continuously for 1,770 minutes and accomplished all objectives. In addition to the high-altitude balloon test, PBS began preparations for a 2016 IST that will perform a hot fire test in a simulated space environment.

Commercial Crew Development

The Commercial Crew Program is facilitating the development of safe, reliable, and cost-effective U.S. human space transportation to and from low-Earth orbit and the ISS. NASA is using a unique approach for this program whereby private industry is responsible for the development of the space transportation systems and NASA is certifying them as safe to transport the Agency's astronauts.

In September 2014, NASA announced contracts with Boeing and SpaceX to continue development and certification efforts under the Commercial Crew Transportation Capabilities (CCtCap) contracts, with a goal of ending the Nation's sole reliance on Russia for crew transportation to and from the ISS. One of the competing corporations subsequently protested the award and, in January 2015, the General Accounting Office rendered a decision in favor of NASA, allowing NASA and the two CCtCap partners (Boeing and SpaceX) to proceed with work in earnest.

During the fiscal year, both commercial partners continued making technical and programmatic progress in maturing their respective commercial crew transportation systems.

- Both partners completed their respective Certification Baseline Reviews, the first major milestone under the CCtCap contracts.
- Throughout the year, both partners continued identifying and submitting variances, alternate standards, and hazard reports necessary for NASA's crew transportation system certification efforts.
- Boeing began modifications to Cape Canaveral Air Force Station's Launch Pad 41 and performed several wind tunnel and landing tests.
- SpaceX completed a pad abort test and continued the company's efforts to modify Launch Pad 39A to enable crewed missions.

Through the Commercial Crew Program, NASA is ensuring that the Agency's commercial partners' crew transportation systems are safe, reliable, and

cost-effective. The certification process assesses progress throughout the production and testing of the partners' systems, which include the launch vehicle, the spacecraft, and ground operations.

Advanced Exploration Systems

The Advanced Exploration Systems (AES) Division is pioneering new ways to rapidly develop prototype systems, demonstrate key capabilities, and validate operational concepts to reduce the risk and cost of future human exploration missions. In FY 2015, the AES Division continued the successful execution of 26 research and technology development activities employing 572 civil servants spread across all NASA Centers. In FY 2015, AES had a goal to complete at least 80 percent of the 72 annual milestones. The team accomplished 56 milestones (78 percent) on schedule and within the available resources.

In November 2014, AES demonstrated the first 3D printer for in-space manufacturing of spare parts and tools on the ISS. The printer produced over 20 parts that returned to Earth for post-flight testing. AES also conducted two public crowdsourcing challenges that involved over 600 students to design a handrail clamp and a container that could be 3D-printed on the ISS.

In December 2014, the AES Radiation Sensors activity flew radiation environment monitors on the EFT-1 mission. These sensors measured the radiation environment inside the Orion crew capsule as it passed through the Van Allen radiation belts. The Radiation Sensors project also completed the Preliminary Design Review for the sensors that will be flown on EM-1.

AES's Automated Systems and Operations activity demonstrated an advance caution and warning system on EFT-1 to help mission controllers identify and diagnose imminent failures in the Orion power system. The activity also developed and tested software for autonomous monitoring and control of a Cascade Distiller System for wastewater processing.

The Bigelow Expandable Activity Module (BEAM) flight hardware arrived at Kennedy Space Center (KSC) in July 2015, after integration of the inflatable module with the Passive Common Berthing Mechanism and the completion of all structural testing and payload safety reviews. A public-private partnership with

Bigelow Aerospace developed BEAM, which is expected to launch to the ISS on the SpaceX-8 mission in January 2016.

AES's Spacecraft Fire Safety project completed the fabrication, assembly, and environmental testing of three Saffire flight experiments that will study large-scale fire propagation in microgravity. The first experiment (Saffire-I) is planned for launch on the Cygnus vehicle in March 2016.

AES issued the Next Space Technology Exploration Partnerships (NextSTEP) Broad Agency Announcement (BAA) in October 2014. This solicitation requested proposals for public-private partnerships to develop habitation and life-support systems, advanced electric propulsion, and small satellites. The partnerships required at least 50 percent cost sharing from industry or universities. AES selected 12 proposals for award in April 2015. Bigelow Aerospace, Boeing, Lockheed Martin, and Orbital ATK received contracts for conceptual studies of habitats beyond Earth orbit. Dynetics, UTC Aerospace Systems, and Orbitec received contracts for life-support-system components. Ad Astra, Aerojet Rocketdyne, and MSNW received contracts to develop 100-kilowatt electric propulsion systems and to test them in the laboratory for 100 continuous hours. Lockheed Martin and Morehead State University received contracts to develop CubeSats for launch as secondary payloads on EM-1.

Working with NASA's Science Mission Directorate and Space Technology Mission Directorate, AES developed systems requirements and preliminary design concepts for three payloads on the Mars 2020 mission to address strategic knowledge gaps for human exploration. The Mars Oxygen In Situ Resource Utilization Experiment (MOXIE) will demonstrate the production of oxygen from the Martian atmosphere to enable in situ propellant production for future human missions. The Mars Environmental Dynamics Analyzer (MEDA) is a surface weather station that will measure temperature, pressure, winds, and dust to characterize the environmental conditions that may be encountered by human explorers. Both MOXIE and MEDA completed their Instrument Accommodation Reviews to ensure their fit on the Mars 2020 rover. In addition, AES committed to re-flying the Mars Entry, Descent, and Landing Instrumentation (MEDLI) experiment to further characterize the entry environment for future landings on Mars by robotic and human missions. The MEDLI-2 project completed its Systems Requirements Review.

AES continued the development of three CubeSats that will be launched as secondary payloads on EM-1. The payloads include Biosentinel, which will investigate the effects of deep space radiation on yeast DNA; the Lunar Flashlight, which will search for volatiles in shadowed craters on the Moon; and the Near-Earth Asteroid (NEA) Scout, which will use a solar sail to fly by an asteroid. BioSentinel completed its biosensor payload Preliminary Design Review, and the Lunar Flashlight and NEA Scout completed their initial safety reviews and developed FlatSat test beds for their spacecraft avionics.

AES's Lunar Cargo Transportation and Landing by Soft Touchdown (Lunar CATALYST) activity worked with three commercial partners to develop lunar landers for delivering small payloads by providing engineering expertise, test facilities, software, and loaned hardware to the partners. In 2015, Astrobotic Technologies completed an end-to-end mission simulation, Moon Express completed a tethered flight of their test vehicle, and Masten Space Systems completed a Preliminary Design Review of their lander's propulsion system.

The AES Resource Prospector continued mission formulation activities this year. AES conducted a field test of a prototype rover carrying a sampling drill and several prospecting instruments in the rock yard at Johnson Space Center (JSC) to simulate mission operations. AES initiated a study agreement with Taiwan to develop design concepts for the Resource Prospector lander.

AES continued to advance next-generation spacesuit capabilities by conducting human-in-the-loop testing of a new Portable Life Support System and assembling a new Z-2 suit garment.

The AES Life Support Systems project completed the Systems Requirements Review for the Spacecraft Atmosphere Monitor that will detect contaminants in the air inside the ISS; the project also completed the Critical Design Review for a Cascade Distiller System that will process wastewater.

The AES Core Flight Software team certified core flight software for use on human spaceflight systems and tested it on the Orion backup computer.

AES demonstrated automated loading of liquid-oxygen and liquid-hydrogen propellants at KSC. AES also demonstrated the liquefaction of hydrogen. This capability will reduce ground-operations costs for fueling the SLS.

An astronaut on board the ISS demonstrated supervisory control of the European Space Agency's Eurobot rover on the ground using Disruption Tolerant Networking communications protocols.

The AES Logistics Reduction activity delivered a Multi-Purpose Cargo Transfer Bag that can be repurposed to provide acoustic insulation around the treadmill on the ISS. AES assembled and tested a Heat Melt Compactor for processing trash.

In collaboration with the U.S. Department of Energy, the AES Nuclear Thermal Propulsion activity fabricated a representative graphite composite reactor fuel element and tested it in a hot hydrogen flow to simulate the environment inside a nuclear rocket engine.

AES matured the Evolvable Mars Campaign (EMC) series of human exploration architecture studies beyond encompassing the capabilities of the ISS, Orion, SLS, short cislunar habitation, and Asteroid Redirect Mission (ARM) to include a broader scope with Agency-wide participation and cooperative robotic mission planning with the SMD. The campaign included the analysis of capabilities realized through the NextSTEP BAA habitation and life-support systems studies, along with emerging plans of international partners. The EMC focused on a hybrid in-space transportation system using solar electric propulsion and chemical propulsion to efficiently transport crew to the Mars environment and back. The Evolvable Mars Campaign will ensure that future architectures have sustainable and resilient capabilities at minimum cost and risk for human spaceflight missions.

AES coordinated multiple integration and strategic planning discussions for Human Exploration and Operations Mission Directorate (HEOMD) leadership and completed the publication *NASA's Journey to Mars: Pioneering Next Steps in Space Exploration* in October 2015. This document, coordinated across the Agency and with external communities, captured and communicated the Agency's human spaceflight plans to domestic stakeholders and the Nation's international partners.

AES funded and co-led the planetary protection workshop for future human missions in March 2015. Planetary protection requirements exist for robotic missions, but there is insufficient scientific and technological knowledge to establish effective quantitative requirements for the development of human spaceflight systems. To prepare for such future missions, HEOMD needed to increase knowledge in microbial and human health monitoring, technology and operations for

contamination control, and natural transport of contamination on Mars while iteratively developing an appropriate set of requirements. The workshop captured the current state of knowledge and identified additional research to appropriately inform planetary protection requirements development for the human exploration of Mars.

Space Life and Physical Sciences Research and Applications

Human Research Program

In 2015, the Human Research Program (HRP) prepared for the release of a Cooperative Agreement Notice for a Translational Research Institute. This institute will replace the current NASA Space Biomedical Research Institute for supporting NASA's human research effort by engaging the skills of the external biomedical research community. The Translational Research Institute is a key component of NASA's strategy to address the key issues in human health and performance for the next generation of space exploration.

The Human Research Program put a major effort into increasing the effectiveness of its utilization of research facilities, beginning with the ISS. Through this effort, HRP removed five investigations from the ISS utilization plan and reduced the on-orbit resource requirements of 14 others. This effort made almost 30 percent of the crew time previously planned for HRP research available for other NASA research. HRP also established partnerships to enable access to unique facilities needed to evaluate risks in long-duration exploration missions. Working with the German Aerospace Center (DLR), HRP arranged access to the :envihab facility in Cologne to conduct long-duration mission simulations. HRP also arranged, through an agreement with the National Science Foundation (NSF), to conduct research on behavioral performance and group dynamics at the NSF's facilities in Antarctica.

ISS Research—Biological and Physical Sciences

The Space Biology Program took major steps toward implementing a vision of broader participation in space research by the biological sciences community with the continuing maturation of the GeneLab project. GeneLab released a

searchable database of existing research results online in 2015, and the GeneLab Data System 1.0 Web site won a 2015 Webby award for ease of navigation out of over 13,000 entries.

In cooperation with the Human Research Program, the Veggie plant research facility grew lettuce that the astronauts aboard the ISS ate. Space Biology plans follow-on demonstrations of crop growth on orbit.

Space Biology initiated the Microbial Tracking project in 2015 to respond to a high-priority recommendation, made by the National Research Council's 2011 Decadal Survey for space life and physical sciences, to conduct an integrated "microbial observatory" investigation of the evolving microbiome of the ISS.

Recognizing the need to achieve greater efficiency in the use of crew time for investigations with large crew-time requirements like rodent research, Space Biology began plans for a cooperative project with a National Laboratory–sponsored investigation. The joint project, tentatively planned for launch in 2017, is expected to return a comprehensive dataset for analysis by the space biology community, maximizing the potential return from these valuable opportunities.

The Cold Atom Laboratory (CAL), a project that aims to create the lowest measurable temperature in the universe aboard the ISS in a facility intended to support a range of world-class investigations in atomic physics, held a successful Critical Design Review on its way to a planned 2017 launch. CAL science team member Holger Mueller (a physicist at the University of California, Berkeley) and colleagues highlighted the possibility of using observations of atomic physics in ultra-cold facilities like CAL to directly observe dark energy, the existence of which has only been inferred from calculations, in a paper published in the journal *Science* in August 2015.

Heat pipes see wide use on Earth and in space to cool electronics, among many heat-transfer applications, but surprisingly little work has been done to observe and understand the behavior of the working fluid that carries the thermal energy inside the heat pipe. In a paper published in the journal *Science* in May 2015, Professor Peter Wayner of the Rensselaer Polytechnic Institute and his colleagues described their observations from a series of experiments with heat pipes aboard the ISS. They observed an unpredicted and unexpected fluid mechanical instability that appears to limit the performance of heat pipes in space-based applications.

With this insight, it may be possible to redesign space-based heat pipes to avoid the instability.

NASA Physical Sciences established, through the Physical Sciences Informatics project, a database with the raw data from a number of flight experiments available online. In its first effort to stimulate broader use of flight results by the research community, NASA released a NASA Research Announcement (NRA) specifically inviting research projects based on the analysis of flight experiment data. The Agency received proposals in October 2015.

Exploration Systems Development

Three programs—SLS, Orion spacecraft, and Ground Systems Development and Operations (GSDO)—are an integrated effort to achieve deep space exploration. The SLS is an advanced launch vehicle for a new era of exploration beyond Earth's orbit, launching astronauts in the Orion spacecraft on missions to an asteroid and eventually to Mars while opening new possibilities for other payloads, such as robotic scientific missions to Mars, Saturn, and Jupiter. GSDO continued preparations at KSC to process and launch the next-generation rocket and spacecraft. Exploration Systems Integration (ESI) continued to integrate the developmental schedules of all three programs to ensure that critical milestones would be met as Exploration Mission–1 moves toward its planned launch window in 2018. Life-cycle reviews across the SLS, Orion, and GSDO proceeded as planned, with the SLS CDR completed in August, Orion's CDR completed in October, and GSDO's CDR planned for late fall 2015.

Orion Program

The Orion Program passed a major milestone with the successful flight of Exploration Flight Test–1 in December 2014. The program designed EFT-1 to take the Crew Module farther from Earth than any human-rated spacecraft has traveled since Apollo, testing the capsule's primary reentry systems, including the heat shield and parachute systems, at conditions far exceeding those experienced during return from low-Earth orbit. Technicians fitted EFT-1 with hundreds of sensors to provide information on loads, acceleration, acoustics, vibration, and other factors that affect vehicle performance and crew survival. The mission also allowed the

Orion and GSDO teams to experience the process of working together throughout assembly, testing, and launch operations and for the Mission Control teams at KSC and JSC to test procedures and handoffs. The results of EFT-1 produced specific improvements in the design and manufacturing process for both the heat shield and the pressure vessel, as well as enhancements in control of the parachute motion upon reentry and the evaluation of improvements to the Crew Module Uprighting System.

Orion also made major progress on flight hardware and test capabilities. In FY 2015, the Orion Program began machining the Exploration Mission–1 Crew Module primary structure, or Pressure Vessel—the living space within Orion. Ahead of the machining and welding of each EM-1 flight part, the program also machined and then welded a pathfinder version to test the design and procedures. The program completed and opened a major test facility, the Integrated Test Laboratory, in Denver during the fourth quarter of FY 2015.

Also in the fourth quarter of FY 2015, Orion passed its Key Decision Point–C review. The data gained from EFT-1 became critical to maturing the preliminary design, allowing the team to advance to its CDR, which was completed on October 21, 2015.

Space Launch System Program

The SLS Program continued to make substantial and sustained progress toward first flight on EM-1. The SLS accomplished two major propulsion test milestones during the reporting period. In 2015, the SLS conducted a series of seven development tests of the RS-25 core stage engine, the first test of an RS-25 since the Space Shuttle Program completed engine testing in 2010. In March 2015, the SLS also successfully conducted the first of two planned booster qualification motor test firings, QM-1.

The SLS Program also made progress on the production capability of the 217-foot-tall core stage flight articles. In January 2015, the SLS discovered a tool alignment problem in the Vertical Assembly Center (VAC) welding tool at the Michoud Assembly Facility in New Orleans, Louisiana, and began remediation; the new date for VAC tool acceptance is now in the first quarter of FY 2016. The VAC

is the largest welding tool of its kind in the world and will enable the assembly of the SLS Core Stage barrel sections using advanced friction stir welding.

The SLS met major design review milestones with the successful completion of CDRs for SLS elements, including the Spacecraft Payload Integration and Evolution CDR-1 in April 2015 and culminating with the successful completion of the SLS program-level CDR in July 2015.

Exploration Ground Systems Program

For the Exploration Ground Systems (EGS) Program, modernization and compatibility efforts continued in FY 2015 to support the EM-1 launch. EGS completed major infrastructure enhancements to prepare launch pad 39B for the EM-1 mission and future flights. Enhancements such as the flame trench, flame deflector, ignition overpressure, and sound suppression system will safely channel the extraordinary energy released by the rocket away from critical systems. To provide ground crew with access to the launch vehicle and Orion while on the mobile launcher, upgrades continued to the aging ground support equipment and umbilical outfitting on the upper stage, core stage, and crew access arm. NASA completed the design for the new adjustable high-bay access in the Vehicle Assembly Building and awarded a construction contract.

As noted earlier, EGS supported Orion EFT-1 landing and recovery operations in FY 2015. EFT-1 completed the under way recovery tests of the EFT-1 mission Crew Module while ongoing landing recovery planning and design continued in support of EM-1. EGS worked on end-to end spaceport command and control system applications and displays, along with transmission, imagery, and voice communication. Integrated verification and validation activity began in order to assure mission success and seamless integration and launch site processing during EM-1.

Science Mission Directorate

The NASA Science Mission Directorate (SMD) and the Nation's science community use space observatories to conduct scientific studies of Earth and the sun from space, to visit and return data and samples from other bodies in the solar system, and to peer into the vast reaches of the galaxy and beyond. SMD's four science divisions—Earth Science, Heliophysics, Planetary Science, and Astrophysics—along with its Joint Agency Satellite Division (JASD) and the James Webb Space Telescope (JWST) program office—contribute significantly to national and Agency goals.

In FY 2015, SMD successfully launched the Soil Moisture Active Passive satellite, the Cloud-Aerosol Transport System, the International Space Station–Rapid Scatterometer (ISS-RapidScat), the Magnetospheric Multiscale mission, the Deep Space Climate Observatory (DSCOVR) satellite, a flight demonstration of a superpressure balloon, eight scientific balloons, and 21 sounding rockets. SMD's research laid the intellectual foundation for future robotic and human expeditions while meeting current scientific needs to address national goals, as well as informing the Nation's decision makers, first responders, and communities by providing observations and predictions on climate and extreme weather, space weather, and potentially hazardous near-Earth objects (NEOs).

Although many of NASA's instruments and spacecraft have exceeded their prime design lifetimes, they continued to provide necessary long-term measurements during this fiscal year. NASA's space assets routinely gathered measurements for operational use by NASA's interagency and international partners. SMD led public engagement in NASA's activities, documenting over 12 billion Twitter impressions in a single week during the Pluto New Horizons flyby. SMD collaborated with NASA's Space Technology Mission Directorate (STMD) to develop new technologies and to study small-satellite potential.

As a part of NASA's commitment to education, SMD's Science Education program enabled NASA scientists and engineers to engage more effectively with learners of all ages. Sally Ride internships have improved retention rates of underserved/underrepresented students in science, technology, engineering, and mathematics (STEM) careers, and a partnership with the Office of Education will expand the

scope of the Undergraduate Student Instrument Project (USIP), which provides undergraduate students with the opportunity to conduct hands-on research. In addition, SMD released the fifth Hands-On Project Experience (HOPE) solicitation for NASA civil service early-career teams to develop a flight project.

Earth Science Division

Through SMD's satellite development, research, applications, and Earth-focused technology advancement programs as well as leveraging continued partnerships with agencies maintaining forecast and decision-support systems (e.g., the National Oceanic and Atmospheric Administration [NOAA], United States Geological Survey [USGS], and Environmental Protection Agency [EPA]), SMD improved national capabilities to predict climate, weather, and natural hazards; to manage resources; and to develop environmental policy. SMD's Earth Science Division (ESD) made essential contributions to understanding global change in service to society.

ESD had numerous successes in FY 2015, including the launch of SMAP to monitor global soil moisture and to study future trends in water availability, the measurement of rapidly transforming Arctic and Antarctic ice regions by Operation IceBridge (OIB), and the onset of both the Orbiting Carbon Observatory 2 (OCO-2) to study carbon's role in climate change and RapidScat to measure surface ocean wind speeds in support of weather forecasting, ocean prediction, and climate studies. The Cloud-Aerosol Transport System launched to the ISS to measure particulate and aerosol impacts, while the Global Precipitation Measurement (GPM) mission, launched in February 2014, produced its first routine global maps of rain and snowfall. NASA started several important Earth Science missions in FY 2015 that are planned for launch in the near future: the Global Ecosystem Dynamics Investigation (GEDI) as the first systematic probe of Earth's forests from space; Landsat-9 to extend NASA's accurate, continuous measurements of Earth's land cover to 50 years; and the Pre-Aerosol, Clouds, and ocean Ecosystem (PACE) mission to advance our understanding of the marine life response to climate change.

During FY 2015, the Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) project made significant technical progress toward a planned launch

in 2017. The Cyclone Global Navigation Satellite System (CYGNSS), designed to study hurricane genesis and intensification using Global Positioning System (GPS) signals reflected from the ocean surface, completed its Mission Critical Design Review. The NASA–Indian Space Research Organisation (ISRO) Synthetic Aperture Radar (NISAR) also successfully completed a key review in its progress toward an unprecedented look at complex Earth processes.

In FY 2015, ESD played a pivotal role in tracking typhoons and providing invaluable information for earthquake disaster relief efforts. NASA sponsored the Global Learning and Observations to Benefit the Environment (GLOBE) Science Education Program. Innovative low- to moderate-cost projects competed under the Earth Venture class of missions. Finally, the Tropical Rainfall Measuring Mission (TRMM) satellite ended a remarkably long-lived 17-year measurement of tropical rainfall, reentering Earth's atmosphere over the southern Indian Ocean.

Antarctic and Arctic Deployments Measure Rapidly Evolving Sea and Land Ice Regions

OIB completed its sixth deployment of research flights over Antarctica to study changes in the continent's ice sheets, glaciers, and sea ice, accomplishing 22 science flights between October and November 2014. During the six-week-long deployment from Punta Arenas, Chile, researchers aboard NASA's DC-8 airborne laboratory measured land and sea ice from above to continue building a record of change in the Antarctic. OIB also completed its seventh Arctic deployment in May 2015, conducting 33 flights comprising numerous science targets, such as the Arctic Basin and Jakobshavn Glacier, and collecting data over sea and land ice regions that have been evolving rapidly over the last decade.

Orbiting Carbon Observatory 2 Studies Carbon Contribution to Climate Change

OCO-2 prime operations officially began in October 2014, and its first data were made available to the public in January 2015, as planned. The satellite gathers detailed global measurements of Earth's carbon (around 100,000 measurements daily) to answer important questions about precisely where carbon is coming from and where it is being stored.

International Space Station–Rapid Scatterometer Measures Ocean Wind Speeds from Space

ISS-RapidScat, which launched on September 20, 2014, has been collecting data following its successful installation and activation on the exterior of the ISS's Columbus module. RapidScat became the first science payload to be robotically assembled in space since the Space Station itself, as well as the first U.S. instrument designed and developed to operate from the exterior of the Station. It is measuring near-surface ocean wind speeds and direction in Earth's low and middle latitudes during its two-year mission to support weather and marine forecasting—including tracking storms and hurricanes—and climate studies.

Terra Satellite Tracks Super-Typhoon Hagupit

The 22nd tropical weather system (and 11th typhoon) of the year in the northwestern Pacific Ocean had the potential to be one of the most damaging of 2014. In early December 2014, Super-Typhoon Hagupit approached the Philippines as a major and slow-moving typhoon threatening to hit the islands with torrential rain and a large storm surge. The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite acquired storm images, and local authorities evacuated hundreds of thousands of people in the lead-up to the storm. At the time, forecasters predicted Hagupit as a Category 5 super-typhoon with sustained winds of 155 knots (180 miles or 290 kilometers per hour) and the fourth Category 5 typhoon of the year in the western Pacific. Forecasters issued the final advisory on Hagupit on December 11–12, 2014, as the Terra satellite tracked the storm's center spinning down off the coast of southern Vietnam. NASA data proved instrumental in informing evacuation efforts.

Optical and Radar Satellites Support Gorkha Earthquake Relief Efforts

NASA data and expertise provided invaluable information for disaster relief efforts in the magnitude 7.8 Gorkha earthquake on April 25, 2015, in Nepal. The quake triggered a humanitarian crisis and significant regional damage. It was the strongest earthquake to occur in the vicinity since the 1934 magnitude 8.0 earthquake, which caused more than 10,000 fatalities. NASA and its partners developed products using optical and radar satellites to support analysis and assessment efforts.

Collectively, the partnership harnessed the best science available, ran models, created maps and tools, and disseminated results to key users to support near-real-time disaster response and recovery.

Cloud-Aerosol Transport System Measures Particulate and Aerosol Coverage Impacting Global Climate

In January 2015, CATS launched to the ISS to measure clouds and the location and distribution of pollution, dust, smoke, and other particulates and aerosols in the atmosphere using a light identification detection and ranging (lidar) system. Using CATS, scientists hope to create a better model of Earth's climate feedback processes.

Soil Moisture Active Passive Satellite Launches to Align Models of Future Trends in Water Availability

Scientists view future water resources as a critical societal impact of climate change; scientific understanding of how such change may affect water supply and food production is crucial for policy makers. Climate model uncertainties have resulted in disagreement on whether there will be more or less water regionally compared to today. The SMAP satellite launched in January 2015. The six-meter-diameter antenna unfurled and deployed in late February. SMAP science operations began in April 2015. NASA released preliminary level 1 data in July, with a full beta set of preliminary calibrated geophysical products scheduled for release in FY 2016. SMAP data enable the alignment of climate models regarding future trends in water resource availability. On July 7, 2015, the SMAP active radar instrument ceased to operate, and all recovery efforts have been unsuccessful. The SMAP observatory and radiometer instrument continue to operate, routinely producing global soil moisture and ocean salinity data with 35-kilometer resolution.

Tropical Rainfall Measuring Mission Satellite Is Remarkably Long-Lived, Measuring Tropical Rainfall for 17 Years

The TRMM satellite, a joint project by the United States and Japan, reentered Earth's atmosphere on June 15, 2015, over the southern Indian Ocean. Designed for a three-year life, the satellite produced valuable data for more than 17 years

(1997 to 2015). TRMM became the first mission dedicated to measuring tropical and subtropical rainfall through microwave and visible infrared sensors, and it included the first spaceborne rain radar. By using a low-altitude orbit of 217 miles (350 kilometers), TRMM's complement of instruments provided more accurate measurements than previously existed. These measurements increased scientists' knowledge of how rainfall releases heat energy that drives atmospheric circulation.

Global Precipitation Measurement Produces First Global Rainfall and Snowfall Map for Global Precipitation Dataset

The GPM mission expands and improves on the TRMM legacy. GPM produced its first global map of rain- and snowfall from its initial months of data collection. By April 2015, the mission had produced the full planned suite of GPM individual and merged data products and made them available to researchers and the operational community. The foundation of the GPM mission is the Core Observatory satellite; data collected from the GPM Core Observatory serve as a reference standard to unify precipitation measurements from research and operational satellites launched by a consortium of GPM partners in the United States, Japan, France, India, and Europe. The GPM constellation of satellites observes precipitation over the entire globe every two to three hours. The GPM Core Observatory measured rain and snow using two science instruments: the GPM Microwave Imager (GMI) and the Dual-frequency Precipitation Radar (DPR). The GMI captured precipitation intensities and horizontal patterns, while the DPR provided insights into the three-dimensional structure of precipitating particles. Together, these two instruments provided a database of measurements against which partner satellites' microwave observations can be meaningfully compared and combined to make a global precipitation dataset.

Gravity Recovery and Climate Experiment Follow-on Programmatic and Technical Maturity

Scheduled for launch in 2017, the GRACE-FO Project successfully completed the final design of all instrument and spacecraft components. Most of the flight hardware has been manufactured, and all three of its science instruments (Microwave Instrument, Laser Ranging Interferometer, and Accelerometers) are

completing final assembly and testing in preparation for delivery for spacecraft integration. GRACE-FO passed its Systems Integration Review (SIR) conducted in July 2015 and Key Decision Point–D in August 2015. NASA designed GRACE-FO to measure variations in gravity over Earth's surface, producing a new map of the gravity field every 30 days to demonstrate how the planet's gravity differs not only from one location to another, but also from one period of time to another.

Cyclone Global Navigation Satellite System Develops Processes to Probe Hurricane Genesis and Intensification

CYGNSS successfully completed its Mission Critical Design Review and KDP-D in August 2015. CYGNSS consists of a constellation of microsatellites scheduled for launch in October 2016. The mission's primary science goal is to better understand how and why hurricane winds intensify by probing key air-sea interaction processes taking place near the inner core of storms, which change rapidly and play significant roles in the genesis and intensification of hurricanes. CYGNSS measurements also may provide information to the hurricane forecast community.

Global Ecosystem Dynamics Investigation Will Provide Unique 3D View of Earth's Forests to Study the Carbon Cycle

The GEDI lidar completed its successful KDP-B in August 2015. GEDI has been designed to be the first systematic probe of Earth's forests from space. The system is one of two instrument proposals selected and started in September 2014 for NASA's Earth Venture Instrument program.

Landsat-9 Project Extends Earth Observations Program to Half a Century

NASA and USGS initiated the Landsat-9 project in March 2015 with plans to launch no later than 2023. The Landsat program has provided accurate measurements of Earth's land cover since 1972. Landsat satellite data have allowed ecologists to track deforestation in South America, water managers to monitor irrigation of farmland in the American West, and researchers to watch the growth of cities worldwide. The program's open archive has helped firefighters to assess the severity of wildfires and scientists to map the retreat of mountain glaciers.

Pre-Aerosol, Clouds, and Ocean Ecosystems to Advance Understanding of Marine Life Response to a Changing Climate

NASA initiated the PACE mission in December 2014, to be executed in a novel design-to-cost approach involving explicit iteration and balancing of mission capabilities, risks, schedule, and costs. Tentatively scheduled to launch in 2022, PACE has been designed to extend critical climate measurements of Earth's oceans and atmosphere and address the uncertainty in our understanding of how clouds and small airborne particles called aerosols affect Earth's climate.

NASA–ISRO Synthetic Aperture Radar Progresses Toward Goal of Unprecedented Look at Complex Earth Processes

This year, the joint NISAR satellite successfully completed its KDP-B review. Using NISAR, scientists hope to learn more about the evolution and state of Earth's crust, better understand our planet's processes and changing climate (manifested through phenomena like ecosystem disturbances and ice-sheet collapse), and aid future resource and hazard management during such disasters as earthquakes, tsunamis, volcanoes, and landslides.

NASA Announces Competition for Innovative Low- to Moderate-Cost Projects for Earth Venture

NASA released the solicitation for the Earth Venture Instrument–3 (EVI-3) in March 2015 and received proposals in June 2015, with selections expected in early 2016. NASA released the Earth Venture Mission–2 (EVM-2) Announcement of Opportunity in September 2015, with selections expected in September 2016. A part of NASA's Earth System Science Pathfinder program, the Earth Venture program encourages investigations using cutting-edge instrumentation carried on airborne platforms, on small space missions, or as secondary instruments or hosted payloads on larger platforms.

NASA Sponsors Global Learning and Observations to Benefit the Environment Science Education Program: Reflecting Commitment to Science, Technology, Engineering, and Mathematics

The GLOBE science and education program, created on Earth Day in 1995, connects students, teachers, and professional and citizen scientists with opportunities to participate in science data collection by conducting real, hands-on science in their local communities. NASA has been one of the proud sponsors of GLOBE since its inception. The 19th GLOBE annual meeting successfully adjourned in July 2015 after a week of discussions between the United States and international partners, as well as GLOBE teachers. A total of 223 students from 33 countries participated, including 29 U.S. students from Alaska, California, Colorado, Ohio, Michigan, and Texas.

Heliophysics Division

Heliophysics improves our understanding of fundamental processes of the sun, which is the major driver of energy in the solar system. The domain of heliophysics is vast, ranging from the interior of the sun, to the upper atmosphere of Earth, and outward to a region far beyond Pluto where the sun's influence wanes against the forces of interstellar space. The sun periodically sends out powerful coronal mass ejections and flares that drive the aurora and powerful electric currents on Earth, inflate the Van Allen radiation belts, violently churn the ionosphere and uppermost layers of the atmosphere, and can disrupt our technologies and be harmful to astronauts.

The Heliophysics Division (HPD) had a fruitful 2015, including the successful launch of the Magnetospheric Multiscale mission to study the little-understood magnetic reconnection phenomenon. Solar Probe Plus (SPP) achieved a key milestone in preparing for its upcoming visit to the sun's atmosphere; Ionospheric Connection Explorer (ICON) completed a design review milestone for its imminent mission of an unprecedented look at how Earth weather impacts space weather; and Global-scale Observations of the Limb and Disk (GOLD) has been confirmed to enter its implementation phase as it prepares to study the atmospheric response to solar forcing. In addition, HPD conducted an external review of 11 CubeSat nanosatellite proposals and launched 21 sounding rockets providing low-cost science opportunities.

Magnetospheric Multiscale Launches to Study Magnetic Reconnection Phenomenon

The MMS mission successfully launched in March 2015 and deployed all four observatories. Science operations began in September 2015, with an expected completion of September 2017. MMS consists of four identical spacecraft orbiting Earth through the dynamic magnetic system surrounding our planet to study a little-understood phenomenon called magnetic reconnection, which occurs when magnetic field lines cross and release a gigantic burst of energy that can be studied only in situ in our solar system and is most accessible in near-Earth space. MMS has already detected its first magnetic reconnection event.

Solar Probe Plus Successful Mission Critical Design Review Preparing to Visit Our Sun's Atmosphere

The SPP project successfully conducted a Mission Critical Design Review in March 2015. SPP is designed to repeatedly sample the near-sun environment, revolutionizing our knowledge and understanding of coronal heating and the origin and evolution of the solar wind, as well as improving our ability to characterize and forecast the radiation environment for future space explorers.

ICON Confirmed for Implementation to Study How Earth Weather Impacts Space Weather

The ICON mission completed its Preliminary Design Review (PDR) and has been confirmed to proceed to its implementation phase (KDP-C). ICON is designed to study the area where terrestrial weather meets space weather (or where the thermosphere and ionosphere overlap) by measuring how motions in the lower atmosphere get transmitted into space at a height of 360 miles for a view of what is happening from the lowest reaches of space up to 250 miles.

Global-scale Observations of the Limb and Disk Mission Moves to Implementation Phase as It Prepares to Study Atmospheric Response to Solar Forcing

The GOLD mission successfully completed its KDP-C and is confirmed to enter the implementation phase. GOLD is an imaging instrument designed to fly on a commercial communications satellite in geostationary orbit to examine the response of the upper atmosphere to forcing from the sun, the magnetosphere, and the lower atmosphere.

Sounding Rockets Provide Low-Cost, High-Risk Science Opportunities

In FY 2015, NASA launched 21 sounding rockets to help calibrate NASA's Solar Dynamics Observatory (SDO) instruments, develop and test new instruments, and conduct experiments on Earth's atmosphere. Since 1959, sounding rockets have proved cost-effective and time-efficient for testing instruments for satellites and spacecraft and providing information about the sun, stars, galaxies, and Earth's atmosphere and radiation.

CubeSat Initiative Furthers Nanosatellite Technology While Attracting Students to STEM Disciplines

This year, the Heliophysics Division conducted an external review of 11 CubeSat (cube-shaped satellite) proposals received in response to the 2017/2018 Human Exploration and Operations Mission Directorate Exploration Mission–1 (EM-1) opportunity. NASA's CubeSat Launch Initiative (CSLI) provides opportunities for nanosatellites (measuring approximately four inches long with a volume of about one quart and weighing about three pounds) to fly as auxiliary payloads on rockets planned for upcoming launches.

Planetary Science Division

Planetary science continues to expand our knowledge of the solar system, with missions to Earth's Moon, other planets and their moons, asteroids and comets, and icy bodies of the outer solar system. Robotic exploration is NASA's principal method of exploring the solar system and an essential precursor to human exploration of space. Ground-based observations and analysis of extraterrestrial materials supplement our space-based assets. Each progression—from flybys, to orbiting spacecraft, to landers and rovers, to sample return missions—advances our understanding of planetary bodies, the chemical and physical history of the solar system, and the conditions for sustaining life.

In FY 2015, the Planetary Science Division (PSD) saw the historic New Horizons flyby of Pluto that completed the initial reconnaissance of the major bodies in the solar system. During Comet Siding Spring's once-in-a-lifetime, extremely close flyby of Mars, NASA spacecraft made atmospheric observations before and after

the comet's arrival to assess the comet's impact on the planet's atmosphere. The Dawn mission went into orbit around the dwarf planet Ceres to study the evolution of our solar system. NASA's mission to Europa passed a key milestone toward its planned search for evidence of conditions suitable for life on Jupiter's icy moon. The Mars 2020 rover successfully completed its KDP-B review and is one step closer to the investigation of Mars's habitability. The Interior Exploration Using Seismic Investigations, Geodesy and Heat Transport (InSight) project completed a review milestone toward its mission to drill deep beneath the Martian surface.

PSD also celebrated several mission milestones. MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) ended a successful four-year mission as the first orbiter of Mercury, impacting Mercury's surface after finally running out of propellant. The unexpectedly long-lived Mars Odyssey completed a major milestone of 60,000 total orbits of Mars since arriving at the Red Planet in 2001. Mars Exploration Rover Opportunity completed the first extraterrestrial marathon (having traveled more than 26.2 miles since landing in 2004), and Mars Rover Curiosity sampled and analyzed sedimentary rocks that scientists believe formed in the presence of water.

From Mountains to Moons: Discoveries by New Horizons' Historic Flyby of Pluto

NASA completed the goal of visiting of all of the major bodies in the solar system with the first-ever flyby of Pluto by New Horizons on July 14, 2015. NASA's New Horizons mission made several discoveries, including icy mountains on Pluto and a new, crisp view of its largest moon, Charon. A new close-up image of an equatorial region near the base of Pluto's bright, heart-shaped feature showed a mountain range made of ice, with peaks jutting as high as 11,000 feet (3,500 meters) above the surface. The mountains on Pluto likely formed no more than 100 million years ago—mere youngsters in a 4.56-billion-year-old solar system—making it one of the youngest surfaces we have ever seen in the solar system and suggesting that the close-up region, covering about one percent of Pluto's surface, may still be geologically active today. NASA celebrated the flyby as one of the Agency's most successful media operations, with Pluto images gracing the front pages of nearly 450 newspapers worldwide on July 15 and appearing in more than 14,000 media reports from July 14 to 20. The Web site nasa.gov reported 18.5 million page views

for July 13–15 alone. On social media, New Horizons tweets and replies made 70 million impressions on Twitter; New Horizons/Pluto posts reached 144 million Facebook users; and all New Horizons posts across 21 social media platforms had a potential reach of 12.1 billion viewers. In the hour before the Pluto flyby, 42 percent of all Government Web traffic occurred at nasa.gov. New Horizons continues to perform well, remaining the top mission page on nasa.gov months after the flyby, with new images and data posted each week.

Very Close Encounters: Comet Siding Spring's Once-in-a-Lifetime Flyby of Mars

Comet Siding Spring's very close approach (within about 87,000 miles [139,500 kilometers]) to Mars took place on October 19, 2014. All Mars orbiters took precautions during the period of greatest risk from dust impacts while preserving opportunities to gather valuable scientific data and obtaining up-close observations of the comet flyby. Mars Atmosphere and Volatile Evolution (MAVEN) and Mars Reconnaissance Orbiter (MRO) made atmospheric observations before and after the comet's arrival to assess the comet's impact on the Martian atmosphere. Dust from the comet impacted Mars and vaporized high in the atmosphere, likely producing an impressive meteor shower. This debris resulted in significant temporary changes to the planet's upper atmosphere and possible longer-term perturbations.

Dawn Mission Orbits Second Celestial Body to Study the Evolution of Our Solar System

In the first visit ever to a dwarf planet, the Dawn spacecraft went into orbit around the dwarf planet Ceres on March 6, 2015. Dawn is the first spacecraft to orbit two different bodies in our solar system. During its nearly decade-long mission, the Dawn mission has completed its study of the asteroid Vesta and is currently studying the dwarf planet Ceres; scientists hope to compare the different evolutionary paths each took and increase our knowledge of how the solar system formed. Vesta is a dry, differentiated object showing signs of resurfacing and resembling the rocky bodies of the inner solar system, including Earth. Ceres, by contrast, has a primitive surface containing water-bearing minerals and perhaps possessing a weak atmosphere, appearing to have many similarities to the large icy moons of the outer solar system.

MESSENGER Impacts Mercury's Surface After Successful Four-Year Mission

After more than four years in orbit, the MESSENGER spacecraft impacted the surface of Mercury on April 30, 2015, ending its successful exploration of the previously never-orbited planet. Traveling at over 8,700 miles per hour (3.91 kilometers per second), the MESSENGER spacecraft collided with Mercury's surface, creating a crater estimated at 52 feet (16 meters) in diameter. MESSENGER acquired over 250,000 images and other extensive datasets during its mission. Among its many accomplishments, the MESSENGER mission determined Mercury's surface composition, revealed its geological history, discovered that its internal magnetic field is offset from the planet's center, and verified the composition of its polar deposits as dominantly water ice.

Europa Mission Prepares to Look for Conditions Suitable for Life

NASA announced instrument selections for a mission to Jupiter's moon Europa in May 2015. The Europa mission passed KDP-A in June 2015 and has proceeded into Phase A. The mission will investigate whether the mysterious icy moon could harbor conditions suitable for life. NASA's Galileo mission yielded strong evidence that Europa, about the size of Earth's moon, has an ocean beneath a frozen crust of unknown thickness.

Mars Reconnaissance Orbiter Confirms That Liquid Water Flows on Mars Today

In September 2015, NASA reported new findings from the MRO that provide the strongest evidence yet that liquid water flows intermittently on present-day Mars. Using an imaging spectrometer, researchers detected signatures of hydrated minerals on slopes with mysterious streaks, known as recurring slope lineae, that darken and appear to flow down steep slopes during warm seasons (when the temperature is above minus ten degrees Fahrenheit [–23 degrees Celsius]) and then fade in cooler seasons. Scientists suspect that the hydrated salts indicate the presence of a liquid brine. The hydrated salts would lower the freezing point of the brine, just as salt on roads here on Earth causes ice and snow to melt more rapidly. Scientists say that the water is likely a shallow subsurface flow, with enough water wicking to the surface to explain the darkening. Earlier in the year, MRO data revealed deposits

of glass within impact craters on Mars, possibly preserving ancient signs of life and opening up a potential new strategy in the search for ancient Martian life.

Mars Exploration Rover Completes First Martian Marathon

On March 24, 2015, or Sol 3968, the Mars Exploration Rover (MER) Opportunity passed the 26.2-mile mark, setting the record as the only vehicle ever to traverse a marathon on the surface of another world. Opportunity's original three-month prime mission in 2004 yielded evidence of past Martian environments with liquid water soaking the ground and flowing on the Red Planet's surface. As the rover continues to operate far beyond expectations for its lifespan, scientists chose the rim of Endeavour Crater as its long-term destination. Since 2011, examinations of Endeavour's rim have provided information about ancient wet conditions less acidic and more favorable for microbial life than the environment found earlier in the mission.

Curiosity Detects Organic Molecules on Mars and Evidence of Ancient Lakes

Using the Sample Analysis at Mars (SAM) instrument suite, NASA's Curiosity rover made the first definitive detection of organic molecules and the first detection of nitrogen on Mars, both of which add to the evidence that ancient Mars could have supported life. Curiosity performed a multipart study of the variation of chemistry within sedimentary rocks on the surface of Mars using the turret-mounted brush and Alpha Particle X-ray Spectrometer (APXS). The Pahrump Hills region contains sedimentary rocks that scientists believe formed in the presence of water. A new study from the team behind NASA's Curiosity has confirmed that billions of years ago, Mars was capable of storing water in lakes over an extended period of time. Using data from the Curiosity rover, the team has determined that, long ago, water helped deposit sediment into Gale Crater, where the rover landed more than three years ago. The sediment was deposited as layers that formed the foundation for Mount Sharp, the mountain found in the middle of the crater today.

Mars 2020 Successful Gate Review: Toward Investigation of Red Planet Habitability

The Mars 2020 Rover mission successfully completed the KDP-B gate review. The Mars 2020 mission is a future rover designed to investigate key questions about

the habitability of Mars, assess natural resources and hazards in preparation for future human expeditions to the Red Planet, and store a collection of rock and soil samples for potential return to Earth.

InSight Completes Project Review

The InSight project completed and passed its Systems Integration Review in February 2015. The InSight mission will place a lander on Mars designed to drill beneath the surface and investigate the planet's deep interior using a seismometer and a heat-flow probe to better understand Mars's evolution as a rocky planet.

Unanticipated Long Life of Mars Odyssey: Achieving 60,000 Orbits Around Mars

In June 2015, the unexpectedly long-lived Mars Odyssey completed the major milestone of 60,000 total orbits of Mars since arriving in 2001. The mission completed the first global map showing the amount and distribution of many chemical elements and minerals composing the Martian surface. Maps of hydrogen distribution led scientists to discover vast amounts of water ice in the polar regions buried just beneath the surface. Odyssey also recorded the radiation environment in low-Mars orbit to determine the radiation-related risk to any future human explorers who may one day travel to Mars. The Odyssey orbiter has also existed as a communications relay for the Mars Exploration Rovers, Spirit and Opportunity, transmitting over 95 percent of the data from the rovers to Earth.

Astrophysics Division

SMD's astrophysics missions explore the extreme physical conditions of the universe and study the building blocks of our own existence at the most basic level: the space, time, matter, and energy that created the universe. Our space telescopes have already measured the current age of the universe to be about 13.7 billion years and uncovered remarkable new phenomena, such as the mysterious dark energy dominating the universe; in the future, they will probe the origin and destiny of the universe, from the first moments after the Big Bang to black holes, dark energy, dark matter, and gravity. Our space missions use nearly the full electromagnetic spectrum to observe the cosmos in our efforts to understand the diversity of planets

and planetary systems in our galaxy. We have confirmed the existence of over 1,900 planets orbiting stars other than Earth's sun and discovered thousands of candidate planets around other stars.

The Astrophysics Division had a successful 2015, with a salute to the breathtaking ongoing work of the Hubble Space Telescope—as it celebrated its 25th anniversary of revolutionizing astronomy—and the Stratospheric Observatory for Infrared Astronomy's (SOFIA) continuing mission as Earth's largest airborne observatory. The Kepler Space Telescope planet-hunting mission announced the discovery of the closest analog yet to an Earth-sun system, while the Chandra X-ray Observatory and Spitzer Space Telescope continued making ground-breaking observations of the universe. This year, the European Space Agency's Laser Interferometer Space Antenna (LISA) Pathfinder, with NASA's Disturbance Reduction System on board, arrived at its launch site; the ISS–Cosmic Ray Energetics and Mass (CREAM) completed testing and arrived at Kennedy Space Center; and JAXA's ASTRO-H observatory with NASA's Soft X-ray Spectrometer completed integration and testing. All three should launch before the end of 2016 or early in 2017. NASA launched an around-the-world test flight of a super-pressure balloon.

Astrophysics also met several milestones: the division cleared the Transiting Exoplanet Survey Satellite (TESS) for its next design phase toward its mission of the first all-sky survey of nearby exoplanets, and the Neutron star Composition and Interior Explorer (NICER) began integration and test activities geared toward a launch to the International Space Station. The Wide-Field Infrared Survey Telescope (WFIRST) had a successful pre-acquisition strategy meeting, and SMD announced the selection of three Small Explorer proposals and two Explorer Mission of Opportunity proposals for competitive Phase A studies. In addition, SMD updated the Astrophysics Implementation Plan to reflect NASA planning and priorities in December 2014.

Hubble Space Telescope: One of the Most Productive Scientific Instruments in History

The Hubble Space Telescope celebrated its 25th anniversary in April 2015 with celebrations and public lectures. Hubble has made more than one million observations, and astronomers using Hubble data have published more than 12,000 scientific papers, making Hubble one of the most productive scientific instruments

ever built. The telescope was initially tasked to measure the expansion rate of the universe, find very distant galaxies, and investigate black holes, but Hubble's research has covered nearly every frontier in deep space astronomy: the expansion and acceleration rate of the universe, the apparent link between galaxy mass and central black hole mass, early galaxy formation shortly after the Big Bang, strange transient events in space, and the chemistry and potential habitability of planets orbiting other stars. Hubble has also provided a fascinating view of Earth's own dynamic solar system, revealing colliding asteroids, showing changing aurorae and weather on planets and moons, and even enabling the detection of previously unknown moons.

Chandra Observes the Hot, Turbulent Regions of the "X-Ray Universe"

The Chandra X-ray Observatory viewed the largest x-ray flare ever detected from the supermassive black hole at the center of the Milky Way Galaxy. Chandra allows scientists from around the world to obtain unprecedented x-ray images and spectra of violent, high-temperature events and objects, helping us better understand the structure and evolution of our universe.

Spitzer's Infrared Observations Peer into Hidden Cosmic Regions

The Spitzer Space Telescope confirmed the discovery of the nearest rocky exoplanet, HD 219134b, a mere 21 light-years away. Spitzer detects infrared radiation, which is primarily heat radiation. Spitzer's highly sensitive instruments allow scientists to peer into cosmic regions hidden from optical telescopes, including dusty stellar nurseries, the centers of galaxies, and newly forming planetary systems, as well as cooler objects in space, like failed stars (brown dwarfs), extrasolar planets, giant molecular clouds, and organic molecules that may serve as signatures of life on other planets.

SOFIA Continues as Earth's Largest Airborne Observatory

Following a successful heavy maintenance visit in late 2014 at Lufthansa Technik in Germany, the SOFIA Observatory conducted a successful six-week science deployment in the Southern Hemisphere while stationed at Christchurch, New Zealand, during the late spring/summer of 2015. SOFIA spent the rest of 2015

conducting science missions from its home base in Palmdale, California. SOFIA is a modified Boeing 747SP and the largest airborne observatory in the world, capable of making observations impossible for even the largest and highest ground-based telescopes. SOFIA is used to study many different kinds of astronomical objects and phenomena, including star birth and death; the formation of new solar systems; the identification of complex molecules in space; planets, comets, and asteroids in our solar system; nebulae and dust in galaxies (ecosystems of galaxies); and black holes at the centers of galaxies.

Kepler Space Telescope Discovers Kepler 452b: Earth's Bigger, Older Cousin

The Kepler Space Telescope discovered Kepler 452b, the closest analog yet to an Earth-sun system. The planet is characterized not as an Earth twin, but as Earth's larger, older cousin. The Kepler planet-hunting mission surveyed a region of the Milky Way Galaxy to discover Earth-sized and smaller planets in or near the habitable zone—the region around a star in which planets with sufficient atmospheric pressure can support liquid water at their surfaces—and determine the fraction of the hundreds of billions of stars in our galaxy that might have such planets. With that survey completed, Kepler is continuing to search for rocky planets around other stars and to study planets in our solar system as well as distance galaxies.

Laser Interferometer Space Antenna Pathfinder Tests Technology Required to Detect "Space Tremors"

The ESA LISA Pathfinder spacecraft, including the NASA Disturbance Reduction System (DRS) instrument, arrived at its launch site in August 2015. This technology demonstration mission is designed to test techniques needed for a future space-based gravitational wave detection observatory. Passing gravitational waves would ripple space and time, revealing their presence by altering the motion of a future observatory's ultrasensitive detectors.

ASTRO-H Orbiting Observatory to Study Extreme Energetic Processes in the Universe

JAXA's ASTRO-H spacecraft, including NASA's contribution to the Soft X-ray Spectrometer (SXS) instrument and Soft X-ray Telescope, completed integration and environmental testing during 2015. ASTRO-H is a facility-class mission

scheduled for launch in early 2016 into low-Earth orbit. The ASTRO-H mission objectives include tracing the growth history of the largest structures in the universe, providing insights into the behavior of material in extreme gravitational fields, determining the spin of black holes and the equation of state of neutron stars, tracing shock acceleration structures in clusters of galaxies, and investigating the detailed physics of jets.

Transiting Exoplanet Survey Satellite Cleared for Next Phase in Design as First All-Sky Survey for Nearby Exoplanets

In October 2014, TESS gained approval to proceed into the manufacturing and assembly phase. This marks a significant step for the TESS mission, which is designed to search the entire sky for nearby planets outside our solar system, known as exoplanets. TESS is expected to find more than 5,000 exoplanet candidates, including 50 Earth-sized planets, and a wide array of exoplanet types, ranging from small, rocky planets to gas giants. Some of these planets could be the right sizes—and orbit at the correct distances from their stars—to potentially support life.

WFIRST Prepares for Investigation of Dark Energy, Galaxy Evolution, Exoplanets

WFIRST conducted a successful pre-acquisition strategy meeting in April 2015 and delivered the final report of the WFIRST–Astrophysics Focused Telescope Assets (AFTA) Science Definition Team, including the Design Reference Mission, in March 2015. The goals for WFIRST include science objectives in exoplanet exploration, dark energy research, and galactic and extragalactic surveys. WFIRST is being designed to have a widefield camera for cosmology surveys and a coronagraph that masks the bright disk of a star so that faint planets near the star can be studied.

Neutron Star Composition and Interior Explorer Closer to Revealing the Physics of Neutron Stars: The Zombies of the Cosmos

NICER accepted delivery of all flight hardware in summer 2015 and should complete payload integration and testing by early 2016 for a 2017 launch. NASA selected NICER in 2014 not only to reveal the physics making neutron stars the densest objects in nature, but also to demonstrate a groundbreaking navigation

technology that could revolutionize the Agency's ability to travel to the far reaches of the solar system and beyond. Neutron stars have been called the zombies of the cosmos: they shine even though they are technically dead, and they occasionally feed on neighboring stars that venture too close.

ISS–Cosmic Ray Energetics and Mass to Measure Cosmic Rays and Their Origin

ISS-CREAM completed integration and environmental testing and was then shipped to Kennedy Space Center in August 2015. ISS-CREAM is designed to be the first instrument to detect cosmic rays at the necessary higher energy ranges and over such an extended duration in space. Scientists hope to discover whether cosmic rays are accelerated by a single cause, believed to be supernovae.

Super-Pressure Balloons Maintain Constant Altitude at the Brink of Space

NASA demonstrated super-pressure balloon (SPB) capability with an around-the-world test flight in mid-latitudes from New Zealand in March–April 2015. NASA conducted additional zero-pressure balloon campaigns from New Mexico, Hawaii, and Antarctica. The SPB is designed to maintain a positive internal pressure and shape irrespective of its environment, keeping the balloon at a constant float altitude. NASA's scientific balloons offer low-cost, near-space access for scientific payloads weighing up to 8,000 pounds for conducting scientific investigations in fields such as astrophysics, heliophysics, and atmospheric research.

Explorer Proposals Selected for Competitive Phase A Studies

SMD announced the selection of three Small Explorer proposals and two Explorer Mission of Opportunity proposals for competitive Phase A studies in July 2015. The Explorer series is designed to provide frequent, low-cost access to space using principal investigator–led space science investigations relevant to NASA's astrophysics and heliophysics programs. The 5 Phase A studies selected included the Polarimeter for Relativistic Astrophysical X-ray Sources (PRAXyS); the Spectrophotometer for the History of the Universe, Epoch of Reionization, and Ices Explorer (SPHEREx); the Imaging X-ray Polarimetry Explorer (IXPE), the Galactic/Extragalactic Ultra-Long Duration Balloon (Gal/Xgal U/LDB)

Spectroscopic–Stratospheric Terahertz Observatory (GUSTO), and U.S. participation in JAXA's LiteBIRD Cosmic Microwave Background Polarization Survey.

James Webb Space Telescope

A large infrared telescope with a 6.5-meter primary mirror, Webb is designed to cover longer wavelengths of light and have greatly improved sensitivity over that of the Hubble Space Telescope, as well as to significantly advance our understanding of the origin and destiny of the universe, the creation and evolution of the first stars and galaxies after the Big Bang, the formation of stars and planetary systems within the Milky Way Galaxy, and the characteristics of planetary systems, including our own.

Webb remains on schedule for launch in October 2018. The program achieved several important milestones during FY 2015, including completion of the second cryo-vacuum test of the integrated science instrument module, the first cryo-vacuum test of the Pathfinder Telescope, the flight telescope backplane and its delivery to Goddard Space Flight Center (GSFC), and the first annual user training in Webb data analysis at the Space Telescope Science Institute.

Joint Agency Satellite Division

In FY 2010, NASA established the JASD within SMD to manage satellite development work for other agencies on a fully reimbursable basis. JASD applies standard NASA project management processes to ensure mission success for our partners, with a focus on the efficient management of operational satellite acquisitions.

In FY 2015, JASD partnered with NOAA and the U.S. Air Force to launch the DSCOVR satellite to measure solar storms before they reach Earth. Four of the five instruments for the first Joint Polar Satellite System (JPSS)-1 mission, which will provide for improved weather-forecasting efficiency and accuracy, successfully completed integration with the spacecraft. NASA, on behalf of NOAA, awarded a contract for the JPSS-2 spacecraft, the follow-on mission to JPSS-1. Additionally, the Geostationary Operational Environmental Satellite–R (GOES-R) spacecraft successfully completed thermal vacuum testing in anticipation of its upcoming launch.

Deep Space Climate Observatory Satellite Positioned to Monitor and Warn of Potentially Harmful Solar Storms

The DSCOVR spacecraft successfully launched on February 11, 2015, and subsequently reached its orbit position (Lagrange point 1)—approximately one million miles away from Earth in the direction of the sun—giving the satellite a unique vantage point on the two bodies. From this location, the satellite is measuring solar storms before they reach Earth. After its commissioning was complete, NASA's Earth Polychromatic Imaging Camera on board DSCOVR returned its first view of the entire sunlit side of Earth from one million miles away. DSCOVR is a partnership between NOAA, NASA, and the U.S. Air Force designed to monitor and warn of harmful solar activity that could impact Earth. JASD completed the spacecraft's Post-Launch Assessment Review in September 2015 in order to formally hand over the DSCOVR spacecraft to NOAA as the new operator. NOAA plans to operate and manage the spacecraft's post-launch commissioning activities until it becomes fully operational and is able to replace the Advanced Composition Explorer (ACE) spacecraft that currently provides the space weather data to NOAA's Space Weather Prediction Center (SWPC).

Joint Polar Satellite System 1 Sets the Groundwork for Improved Efficiency and Accuracy in Weather Forecasting

In 2015, the JPSS-1 satellite made significant progress by successfully completing its Mission System Integration Review and Mission Operations Review, setting the groundwork for the satellite's mission of improving weather-forecasting efficiency and accuracy. JPSS is the restructured civilian portion of the National Polar-Orbiting Operational Environmental Satellite System (NPOESS). The system includes satellites and sensors supporting civil weather and climate measurements and a shared ground infrastructure with the Department of Defense weather satellite system.

GOES-R Completes Thermal Testing in Anticipation of Upcoming Launch

The GOES-R spacecraft successfully completed its Pre-Environmental Review in April 2015 and thermal vacuum testing in September 2015. GOES is a joint NASA-NOAA effort consisting of a series of four next-generation geostationary

weather satellites designed to help meteorologists observe and predict weather events, including thunderstorms, tornadoes, fog, flash floods, and other severe weather. The first satellite of the GOES-R series is scheduled to launch in 2016.

Jason-3 to Monitor Earth's Oceans and Predict Cyclone Intensity from the Vantage Point of Space

The Joint Altimetry Satellite Oceanography Network (Jason)–3 mission successfully completed its Operations Readiness Review and the spacecraft pre-ship review. The mission also successfully completed several launch-vehicle readiness reviews in preparation for an initially planned August 2015 launch date. However, the new launch readiness date has been pushed to January 2016, pending the outcome of the SpaceX CRS-7 launch failure investigation. Jason-3 continues a 23-year effort to monitor Earth's global ocean: tracking sea-level rise, ocean heat content, and sea-surface height. Jason-3 is an international partnership led by NOAA with participation from NASA, France's Centre National d'Études Spatiales (CNES), and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT).

International Cooperation Results in Meteorological Operational Satellite Program–C

The Meteorological Operational Satellite Program (MetOp)–C mission successfully completed an annual activation test on its payload module; the U.S.-provided instruments performed nominally. The payload module has been returned to storage until the launch readiness date, currently planned for October 2018. MetOp is a European meteorological satellite network (with MetOp-A and MetOp-B currently operating on orbit) and the result of multinational cooperation and teamwork.

Aeronautics Research Mission Directorate

The Aeronautics Research Mission Directorate (ARMD) implemented a new program structure in FY 2015 to align with the new ARMD strategic vision described in the FY 2014 NASA Strategic Plan. The restructured organization most effectively manages the research needed to address the six new strategic research thrusts: safe, efficient growth in global operations; innovation in commercial supersonic aircraft; ultra-efficient commercial vehicles; a transition to low-carbon propulsion; real-time, systemwide safety assurance; and assured autonomy for aviation transformation. The new structure includes four programs committed to transforming aviation: the Airspace Operations and Safety Program, the Advanced Air Vehicles Program, the Integrated Aviation Systems Program, and the Transformative Aeronautics Concepts Program.

In FY 2015, NASA celebrated the 100th anniversary of the establishment of the National Advisory Committee for Aeronautics, the organization from which NASA was created in 1958, marking the Agency's long research heritage in advancing airframe and engine technologies. Many of the technological advances realized during the past fiscal year can trace their origins to lessons learned about aviation during the past century. More information is available online at *http://www.nasa.gov/naca100* and *http://www.nasa.gov/aero/airplanes-or-langleys-and-other-tales-of-the-NACA*.

Airspace Operations and Safety Program

During FY 2015, NASA contributed specific research and technology to enable the continued development of the Next Generation Air Transportation System (NextGen) and beyond and to address current and future safety risks.

Two NASA-developed software tools for helping the Federal Aviation Administration (FAA) better manage air traffic through the National Airspace System (NAS) moved from concept to reality during FY 2015. One of these tools, Terminal Sequencing and Spacing (previously called TSS, now TSAS), helps air traffic controllers manage airspace within a doughnut-shaped region of sky that begins five miles from a major airport and extends outward about 35 miles and

allows pilots to better use flight deck automation to fly fuel-efficient, optimized-profile descents, which streamlines glide paths toward the runway, reducing fuel use and approach noise to an airport. TSAS safely permits more flights to merge together at a point where they can be cleared for final approach and landing. The FAA and NASA completed an operational integration assessment of the tool in May 2015 at the FAA's William J. Hughes Technical Center. The FAA received a final investment decision for the program, meaning that the agency intends to deploy the capability in the NAS beginning with nine major airports located in Phoenix, Houston, Atlanta, Seattle, San Francisco, Las Vegas, Charlotte, Denver, and Los Angeles between 2018 and 2022. More information is available online at *http://www.nasa.gov/press-release/nasa-developed-air-traffic-management-tool-flies-into-use*. The other tool, Airborne Spacing for Terminal Arrival Routes (ASTAR), gives pilots specific speed information and guidance so that planes can be more precisely spaced, enabling pilots to fly a "follow the leader" approach to their destination airport. This type of approach would minimize flightpath deviations, allow more efficient use of existing airspace, and possibly reduce noise over communities surrounding airports—all of which could lead to reductions in commercial flight delays. NASA tested the software on the Boeing ecoDemonstrator 787 Test Airplane as part of the Boeing Company's ecoDemonstrator Program. During the flight tests, a NASA engineer operated ASTAR on a laptop in the rear of the aircraft. As a second aircraft flew in front of the ecoDemonstrator 787, ASTAR computed and displayed the speed required to follow safely behind. The engineer then communicated those speed commands to the ecoDemonstrator 787 pilots. This demonstration is part of the lead-up to flight trials for the Air Traffic Management Technology Demonstration #1 expected in 2017. More information is available online at *http://www.nasa.gov/press/2014/december/nasa-tests-software-that-may-help-increase-flight-efficiency-decrease-aircraft/*.

A third tool, known as Traffic Aware Planner (TAP), helps air carriers save time and reduce fuel consumption and carbon emissions. During FY 2015, Virgin America and Alaska Airlines adopted the tool for testing by their pilots during the next three years. TAP connects directly to the aircraft avionics information hub on the aircraft and reads the current position and altitude of the aircraft, its flight route, and other real-time information that defines the plane's current

situation and active flight plan. Then, it automatically looks for a variety of route and/or altitude changes that could save fuel or flight time and displays those solutions directly to the flight crew. TAP also can connect with the plane's Automatic Dependent Surveillance–Broadcast (ADS-B) receiver and scan the ADS-B signals of nearby air traffic to avoid potential conflicts in any proposed flightpath changes, making it easier for air traffic controllers to approve a pilot's route change request. More information is available online at *http://www.nasa.gov/press-release/nasa-developed-technology-aims-to-save-commercial-airlines-fuel-time*.

Also during FY 2015, NASA continued its research in the phenomenon of ice crystal icing conditions at high altitude. When ice crystals hit warm aircraft engines, they start to melt and evaporate, cooling the engine core surfaces to temperatures below freezing. The cooling engine causes the melted ice crystal water to refreeze, and ice accumulates inside the engine core, which may cause temporary power loss or engine blade damage. During the month of August, NASA's DC-8 completed flights in Florida aimed at collecting data on high-altitude crystals for the High Ice Water Content (HIWC) mission. The campaign collected almost 72 hours of in-flight meteorological and radar data associated with adverse weather and thunderstorms. This NASA-led research campaign, which also involved the FAA, the Boeing Company, and other industry partners, recorded both instrumented weather and standard radar data as the plane flew in known HIWC conditions, and, then, it saw if a potential HIWC radar signature could be identified by comparing the data. Researchers plan to use the data to develop technology that can be used on board commercial aircraft to avoid high-ice-water-content conditions and provide a safer flight for passengers. More information is available online at *http://www.nasa.gov/aero/nasa-completes-high-ice-water-content-radar-flight-campaign-in-florida*.

Public attention to unmanned aircraft systems and their growing presence in the NAS stimulated widespread interest in a conference cohosted by NASA and held during July 2015 in California. The three-day Unmanned Aircraft Systems (UAS) Traffic Management (UTM) convention brought together a domestic and international audience of representatives from Government and academia, as well as the aviation, agriculture, and film industries, among others. Through discussions held at this conference, and with others, NASA worked toward developing a well-coordinated plan for incorporating UTM operations into the NAS to inform

regulatory actions taken in the future by the Federal Aviation Administration. Then, in late August, NASA's UTM project successfully completed its Build 1 Demonstration flight test. Objectives included demonstration of UTM capabilities/procedures, navigation performance, and aircraft tracking. The project collected data on noise signatures and observations for weather models.

Advanced Air Vehicles Program

The Agency kicked off the calendar year at a public forum in Florida in which NASA shared results from the previous spring's second round of Alternative Fuel Effects on Contrails and Cruise Emissions (ACCESS II) research flights. Forum attendees included many of the 24 member nations that make up the International Forum for Aviation Research (IFAR). Several IFAR members partnered with NASA for the ACCESS II research. It was the first time NASA was able to brief IFAR members since project researchers had announced initial results the previous September. The ACCESS II campaign used NASA's DC-8, burning biofuel and Jet-A, and aircraft from two partner nations, Germany and Canada, to fly sampling missions. The campaign also completed ground sampling of emissions from an idling DC-8. Data from this ACCESS II test, as well as from predecessor tests, are publicly available online at *https://aero-fp.larc.nasa.gov*. More information is available online at *http://www.nasa.gov/aero/nasa-reports-alternative-jet-fuel-research-results.html*.

In FY 2015, NASA completed a set of performance milestones in commercial supersonic aircraft research that represent the culmination of more than six years of work by a multi-Center NASA team, supported by U.S. partners in industry and academia. The work delivered new computational tools and design approaches that have created a breakthrough capability to design supersonic aircraft adept at flying overland without creating annoying sonic-boom noise. These tools can fully simulate the supersonic flow around an aircraft, including details of the flow and the sonic-boom shock wave that are affected by the engine inlet and nozzle. Wind tunnel testing validated the analysis tools in a variety of facilities. The tools and design approaches have been transferred to NASA's U.S. industry partners and applied in the successful conceptual design of small supersonic civil airliners and a

subscale low-boom X-plane that could be used to demonstrate the acceptability of low-boom supersonic flight over land.

In support of this ongoing development of commercial supersonic technology, NASA continued its efforts related to another challenging environmental problem for commercial supersonic vehicles—propulsion noise generated while the vehicle is at the airport. In FY 2015, NASA developed models of the types of advanced nozzles needed for a small, low-boom aircraft to predict the noise generated by the propulsion system. Future testing should validate the accuracy of these models. Additionally, industry and university research studies complemented these efforts to further address sonic-boom propagation, nozzle noise, and high-altitude emissions from supersonic jets. More information is available online at *http://www.nasa.gov/press-release/nasa-invests-in-future-of-aviation-with-supersonic-research-projects*.

In FY 2015, NASA also completed testing on an advanced, hybrid wing body aircraft configuration that has significant potential to be more efficient in flight—dramatically reducing needed fuel. The configuration also included mounted engines located on top of the vehicle rather than below the wing as is done currently. NASA completed this testing in the National Transonic Wind Tunnel at NASA Langley Research Center in Virginia in partnership with another Government agency and an airframe manufacturer. Additionally, in FY 2015, NASA completed the designs for significantly enhanced optical access ports for the 11-foot and 9- by 7-foot (9×7) Wind Tunnels at Ames Research Center in Moffett Field, California. Key components have been acquired, and, when complete, the visibility into the wind tunnel test sections should greatly enhance understanding of the flows affecting the models of next-generation, highly fuel-efficient aircraft.

Because lighter-weight aircraft are generally more fuel-efficient than heavier ones, NASA is investing in advancing lightweight composite materials for aircraft. In FY 2015, NASA made advances in bringing computational modeling and prediction capabilities to bear on the challenge of fully exploiting the potential of these composite materials. Specifically, NASA conducted detailed testing and inspection of various types of damage that may affect composite structures and is preparing to compare these data with calculated predictions of such damage. The ability to predict how such damage may occur and progress would enable more confidence in the use of composite materials in advanced aircraft design and manufacturing.

Working toward ultra-efficient vehicles also requires the advancement of technologies to address other environmental factors, such as noise. In the area of vertical-lift (rotorcraft) vehicles, in FY 2015, NASA conducted flight tests using a pair of helicopters to validate a computer-based model known as Fundamental Rotorcraft Acoustic Modeling for Experiments (FRAME), which predicts when and where rotorcraft noise might become a problem as the vehicle flies in different conditions and altitudes. Results of the flight testing enabled the validation of this prediction tool, which in turn should enable onboard tools and techniques to allow helicopter pilots to adjust their flight profiles based on readily available information on how the noise signature is hitting the ground. More information is available online at *http://www.nasa.gov/langley/nasa-researcher-develops-model-that-could-quiet-down-noisy-helicopters* and *http://www.nasa.gov/langley/feature/nasa-langley-honored-for-landmark-contributions-to-vertical-flight*.

In FY 2015, NASA conducted research in hybrid gas-electric propulsion system concepts that could enable very-low- or nearly no-carbon emission propulsion. Detailed design began for the first fully superconducting machine (with both a superconducting rotor and stator) at power levels of interest to designers of aircraft. This 0.75-megawatt machine is based on a heritage Air Force rotor and NASA-designed stator. Additionally, NASA established feasibility for achieving substantially high efficiencies and power densities in nonsuperconducting motors, which hold potential for hybrid gas-electric aircraft without the need for cryogenics. NASA also completed laying the foundation for two new test bed capabilities. The first, located at Armstrong Flight Research Center, is designed to investigate the power and control design and integration challenges associated with a one-megawatt hybrid electric vehicle. The second, located at Glenn Research Center, is designed to provide the capability to test megawatt-class electric drive systems.

At the end of FY 2015, NASA collaborated with the German Aerospace Center (DLR) by supplying several key measurement instruments for the DLR's Emissions and Climate Impacts of Alternative Fuels (ECLIF) experiments. NASA has designed and installed an exhaust sampling system and provided detailed particle emission characterization measurements for the ground tests, the results of which should help interpret the airborne observations and validate a model to predict cruise emissions from engine certification measurements. Under this

activity, NASA placed instruments about 100 feet (30 meters) behind a parked DLR Airbus 320. These instruments then measured the exhaust from the jet as it burned eight different types of standard and alternative fuels that contained varying amounts of aromatic compounds and sulfur impurities. Emissions covering a total of about nine hours of ground-based jet engine operations were sampled, and the data were recorded and analyzed as part of NASA's contribution to the German-led effort. Data analysis is getting under way, but preliminary results appear consistent with those from ACCESS-II and indicate that fuels with reduced aromatic and sulfur content produce lower particle emissions. ECLIF data should help confirm and supplement information gathered during NASA's own research with the Alternative Aviation Fuel Experiment (AAFEX) activities in 2009 and 2011 and during the ACCESS flight research campaigns in 2013 and 2014. More information is available online at *http://www.nasa.gov/aero/nasa-instruments-head-to-germany-for-alternative-fuels-research*.

Integrated Aviation Systems Program

During FY 2015, NASA's Environmentally Responsible Aviation Project concluded its final year with eight successfully completed Integrated Technology Demonstrations that enable industry to build advanced, ultra-efficient commercial vehicles. For airplanes flying in the 2020–25 timeframe, NASA research is aimed at cutting fuel use in half, reducing emissions up to 75 percent during takeoff and landing, and quieting aircraft noise by 42 decibels below current standards.

Two of these demonstrations took place this year aboard Boeing's ecoDemonstrator 757 flying laboratory. The first studied how small jets embedded in an aircraft's vertical tail and blowing air over its surfaces could provide enough force to safely allow smaller tails on future aircraft designs, resulting in saved weight, reduced drag, and a decrease in fuel usage of up to 0.5 percent—a small number that quickly adds up to big savings. The project tested active flow control technology during six flights in a variety of configurations and flight conditions—including simulated engine failures—which appeared to work as expected, duplicating the results of wind tunnel tests conducted in

2013. More information is available online at *http://www.nasa.gov/press-release/nasa-wraps-up-first-green-aviation-tests-on-boeing-ecodemonstrator.*

The second demonstration studied how well special coatings worked to prevent sticky bug residue from building up on the leading edge of an airplane wing and increasing drag. Fewer remains would smooth airflow and help reduce fuel consumption. NASA and Boeing engineers made 15 flights into bug-filled skies near Shreveport Regional Airport testing nonstick wing coatings. Although more testing needs to be done, one of the five coatings tested showed promising results by reducing bug counts and residue about 40 percent. More information is available online at *http://www.nasa.gov/langley/nasa-tests-aircraft-wing-coatings-that-slough-bug-guts*.

Ever-increasing levels of automation and autonomy are transforming aviation. Safe integration of Unmanned Aircraft Systems—colloquially known as drones—into the National Airspace System requires research in multiple areas, including communications, human-machine interfaces, sense-and-avoid, and separation assurance. NASA's aeronautical innovators addressed each of these areas during FY 2015. In May 2015, the Radio Technical Commission for Aeronautics–Special Committee 228 (RTCA-SC228) held working group meetings in Washington, DC, at which NASA's UAS in the NAS project representatives participated. The special committee is responsible for developing Minimum Operational Performance Standards (MOPS) for flying UAS in the NAS. NASA researchers provided input including data, analysis, and recommendations based on integrated flight tests involving both simulated and live vehicles traversing airspace and interacting with other aircraft. Section areas briefed for the committee's report included guidance, alerting, human-machine interface, aircraft performance, terminology, system-specific performance requirements, and equipment test procedures. The Preliminary MOPS incorporated this information, which the RTCA Program Management Council approved in FY 2015.

UAS activity for FY 2015 wrapped up with the successful demonstration of a prototype Detect-and-Avoid (DAA) system using NASA's remotely piloted Ikhana aircraft. Ikhana made 11 flights over the California high desert involving more than 200 scripted encounters with approaching aircraft. Depending on the specific scenario, either Ikhana detected one or more approaching aircraft and sent an alert to its remote pilot to take action, or Ikhana itself took action on its own by

flying a programmed maneuver to avoid a collision—an aviation first. The DAA research, designated FT3 (for third in a series of flight test campaigns for NASA's UAS Integration in the NAS project), relied on three sensors that included a prototype radar, an ADS-B, and a second-generation Traffic alert and Collision Avoidance System (TCAS). As its name implies, TCAS keeps an electronic eye on the sky immediately surrounding an airplane and alerts the pilot to take action if another airplane with a similar device flies too close. Knowledge gleaned from the data recorded during this third phase of UAS-NAS flight tests should not only help researchers plan the next phase of flight tests targeted for FY 2016, but also help inform organizations developing UAS-related operating standards, including the RTCA-SC228.

Transformative Aeronautics Concepts Program

Safety is the highest priority in aviation, so the quest for reducing risk in the air is never-ending. An example of NASA's devotion to anticipating and resolving potential safety issues dealt with the presence of volcanic ash in the atmosphere and its effects on engine health. During FY 2015, the Vehicle Integrated Propulsion Research (VIPR) project chose to use volcanic ash for the final phase of a three-phase study of an engine health–monitoring system. Atmospheric particulates have become of interest to military and civil aviation authorities that have to assess the airworthiness of engines encountering ash. Eruptions in Iceland during the past five years, especially in 2010, disrupted air traffic worldwide and cost airline companies more than $1 billion due to cancelled or rerouted flights. The new health-monitoring sensors detect the degradation caused by the volcanic ash, quantify the significance of the event, and aid in identifying which engine components might require maintenance. To reduce risk, the VIPR project conducted tests on the ground under controlled conditions. More information is available online at *http://www.nasa.gov/centers/armstrong/features/engine_health_monitoring.html*.

Space Technology Mission Directorate

The Space Technology Mission Directorate (STMD) made significant progress toward advancing NASA's current and future deep space exploration missions. In order to enable and enhance the Agency's capabilities, investments focused primarily in eight key thrust areas: 1) In-Space Propulsion; 2) High Bandwidth Space Communications; 3) Advanced Life Support and Resource Utilization; 4) Entry, Descent, and Landing (EDL) Systems; 5) Space Robotic Systems; 6) Lightweight Space Structures; 7) Deep Space Navigation; and 8) Space Observatory Systems. STMD manages nine major technology development programs performed at each of NASA's ten Centers. STMD plays a key role in NASA's contribution to the Nation's innovation economy through involvement in several national initiatives, including the Advanced Manufacturing Partnership and the National Robotics Initiative.

In FY 2015, STMD fostered 61 activities with 42 other Government agencies and ten activities with 14 international organizations. STMD also evaluated over 2,500 proposals and funded over 650 new selections for awards investing over $200 million. A few of the notable achievements in FY 2015 included the following:

Technology Demonstration Missions

Low Density Supersonic Decelerator

The Low Density Supersonic Decelerator (LDSD) crosscutting demonstration mission successfully conducted its second full-scale flight test of a rocket-powered, saucer-shaped vehicle in near-space on June 8, 2014, from the U.S. Navy's Pacific Missile Range Facility on Kauai, Hawaii. Following up on the earlier test flight, FY 2015's flight served as a crucial milestone for proving two key technologies for landing future robotic and human missions on the surface of Mars: the Supersonic Inflatable Aerodynamic Decelerator (SIAD) and the Supersonic Ringsail parachute. At 180,000 feet and supersonic speeds of about Mach 3, the SIAD, a large doughnut-shaped air brake, deployed flawlessly during the flight and began to slow the vehicle. The state-of-the-art supersonic parachute—at 100 feet in diameter, the largest parachute ever flown—appeared to blossom to full inflation prior to

the emergence of a tear, which then destroyed the parachute's canopy. The team recovered all the vehicle hardware and data recorders for analysis.

Solar Electric Propulsion

NASA's Solar Electric Propulsion (SEP) project is developing critical technologies to enable cost-effective access across the inner solar system to destinations such as Mars and asteroids. SEP technology can also support more affordable missions for commercial and Government operations in Earth orbit. The system uses energy collected by large solar-cell arrays that convert it to electrical power. The electrical power drives extremely fuel-efficient thrusters that provide gentle but continuous thrust throughout the mission. Previously, ATK Aerospace and Deployable Space Systems, working with NASA, completed ground testing of large, high-power solar arrays that can be stowed into small, lightweight packages for launch. One of these concepts has already been adopted for use on commercial satellites. In FY 2015, the SEP team at NASA's Glenn Research Center successfully tested a new 12.5-kilowatt Hall thruster throughout its full performance envelope. This electric thruster employs magnetic shielding that enables it to operate continuously for years, a capability needed for deep space exploration missions.

Green Propellant Infusion Mission

NASA's Green Propellant Infusion Mission (GPIM) made progress toward launching a spacecraft designed to test the unique attributes of a high-performance, nontoxic, "green" fuel on orbit next year. The propellant, a hydroxyl ammonium nitrate–based fuel/oxidizer mix also known as AF-M315E, may replace the highly toxic hydrazine and complex bipropellant systems in use today, providing enhanced performance and volumetric efficiency. In FY 2015, GPIM prime contractor Ball Aerospace & Technologies Corp. in Boulder, Colorado, integrated the green propellant propulsion subsystem less than two weeks after receiving it from Aerojet Rocketdyne in Redmond, Washington. The propulsion subsystem is the primary payload on the mission's spacecraft—a Ball Configurable Platform 100 small satellite. System performance and environmental testing has already begun, and launch to low-Earth orbit in partnership with the U.S. Air Force is scheduled for early 2017.

Deep Space Atomic Clock

The Deep Space Atomic Clock (DSAC) project continued advancing toward its test flight next year, completing a Critical Design Review and KDP-D. The project completed clock integration as well as functional and performance testing, vibration testing, and thermal vacuum testing. The full payload testing is under way, and launch as part of the U.S. Air Force's Space Test Program (STP)–2 mission aboard a SpaceX Falcon 9 Heavy booster is expected in early 2017. Surrey Satellite Technologies U.S. of Englewood, Colorado, is providing a spacecraft to host the DSAC demonstration unit and payload.

Laser Communication Relay Demonstration

The Laser Communication Relay Demonstration (LCRD) project also continued to surpass developmental milestones on its way to conduct ground technology validation testing in 2017 and will fly as a commercial satellite payload in 2019. Ground Modem #1 successfully demonstrated optical communication with the Massachusetts Institute of Technology (MIT) Lincoln Laboratory, and the assembly of Ground Modem #2 was completed.

Game Changing Development

The Game Changing Development (GCD) program engaged industry, students, members of the public, and stakeholders across a variety of technical areas, producing over 220 publications and presenting at 65 conferences in FY 2015.

Next Generation Life Support

The Next Generation Life Support (NGLS) project seeks to develop key life-support technologies that will enable critical capabilities to extend human presence beyond low-Earth orbit into the solar system. In FY 2015, the project successfully developed two portable life-support system technologies—the Rapid Cycle Amine unit and Variable Oxygen Regulator—for the next-generation extravehicular mobility unit, which will be infused in HEOMD's Advanced Exploration Systems demonstrations.

High-Performance Thermal Protection Systems

In FY 2015, GCD successfully developed and matured the 3-Dimensional Multifunctional Ablative Thermal Protection Systems (TPS) (3D-MAT) for use in spacecraft heat shields. The 3D woven composite has pushed state-of-the-art manufacturing to new levels, yielding tailored materials that can be both structure and thermal protection system. The technology has been infused into the baseline design of the Orion Multi-Purpose Crew Vehicle as the compression pads, the interface between the crew module and service module for the EM-1 flight planned for 2018.

Thermal Systems

During the course of FY 2015, GCD's Phase Change Material (PCM) Heat Exchanger (HX) project set out to design and develop large-scale PCM heat exchangers for future exploration vehicles. As missions move beyond low-Earth orbit, human spacecraft orbiting the moon or Mars will need some form of supplemental heat rejection to accommodate cyclical heat loads. In partnership with Mezzo Technologies in Baton Rouge, Louisiana, and UTC Aerospace Systems in Windsor Locks, Connecticut, GCD developed and fabricated advanced PCM HXs for flight demonstration on the International Space Station in 2016. The PCM HX feeds into the thermal control system design for Orion.

Human Robotic Systems

This project develops advanced robotic technology to amplify human productivity and reduce mission risk by improving the effectiveness of human-robot teams. Key technologies include human-robot interaction, robotic assistance, and surface mobility systems. In FY 2015, Human Robotic Systems (HRS) designed and fabricated a prototype rover in support of HEOMD's Resource Prospector project. This mission, currently planned to fly in 2020, should demonstrate prospecting and processing volatiles (potentially water ice trapped below the surface) from lunar regolith.

Small Business Innovation Research (SBIR) and Small Technology Transfer Research (STTR)

NASA awarded 532 proposals for a total of $166.9 million in FY 2015. Specifically, NASA selected 332 SBIR and 50 STTR Phase I proposals for award to 327 U.S. small businesses to establish the scientific, technical, and commercial feasibility of the proposed innovation. In addition, NASA made 129 SBIR and 21 STTR Phase II awards to further expand upon their Phase I work. Furthermore, the Commercialization Readiness Program (CRP) awarded 17 CRP contracts for $5.4 million in FY 2015. SBIR/STTR CRP investment to date totals $9 million. A few highlights from FY 2015 awardees include the following: PC Krause and Associates has developed technology to enable dynamic modeling of the N+3 generation aircraft, investigation of aircraft configurations, estimation of mass and efficiency, and fault/stability assessment. Busek Company, Inc., matured propulsion technologies to support future CubeSat and other space exploration missions. The Heatshield for Extreme Entry Environment Technology Project (HEEET) matured Bally Ribbon Mills' 3D woven thermal protection system material for demanding future entry/reentry missions. Creare, Inc., worked on developing and demonstrating the fabrication processes for a prototype heat exchanger module for a 20-kelvin, 20-watt cryocooler to enable future science missions.

Small Spacecraft Technology Program

This program has been preparing for demonstration missions related to all of its current flight projects. The Optical Communications and Sensor Demonstration project launched one CubeSat on October 8, 2015, and plans for two more in June 2016. In FY 2015, SSTP completed spacecraft integration and pre-flight testing for the Integrated Solar Array Reflectarray Antenna satellite for advanced communications as well as the CubeSat Proximity Operations Demonstrator that will attempt autonomous rendezvous and docking. The program has been formulating a series of future CubeSat missions to demonstrate propulsion capabilities. In FY 2015, the program completed 11 university-NASA collaboration projects and selected eight new projects for 2016–17. Two of the earlier projects developed satellites that were selected for NASA-sponsored launches.

Flight Opportunities

The Flight Opportunities Program flew 29 technology payloads over the course of five parabolic and eight suborbital reusable launch vehicle (sRLV) test flights in FY 2015. Among the technologies tested, Masten Space Systems flew the Jet Propulsion Laboratory's (JPL) Fuel Optimal and Accurate Landing System Test Flights (FOALS). FOALS progressed one step closer to the Mars 2020 mission. Another successful test flight included UP Aerospace Corporation's launch of SpaceLoft-9 with four payloads, including a Montana State University project designed to mature the technology readiness level of a radiation-tolerant, reconfigurable computer system. The Flight Opportunities Program also selected six technologies for flight demonstration grants through the STMD Research, Development, Demonstration, and Infusion 2014 (REDDI-2014) NASA Research Announcement (NRA) and on-ramped New Space Corporation as a new flight provider under the Agency's indefinite-delivery, indefinite-quantity (IDIQ2) contract. The program also released a call for sRLV and nanolauncher public-private partnership opportunities.

Space Technology Research Grants

The Space Technology Research Grants Program has funded research at 95 universities across 42 states with a total of 357 grants since its inception. Some highlights from FY 2015 include the following:

- Erik Komendera, a researcher from the University of Colorado Boulder, demonstrated autonomous assembly of 2D titanium trusses using intelligent precision, jigging robots, laser sensing, and welding.
- Christopher Combs, a researcher from the University of Texas at Austin, acquired quantitative images of the transport of the ablation products in a supersonic turbulent boundary layer on a scaled Orion Multi-Purpose Crew Vehicle–shaped model; NASA is using these data for computational fluid dynamics validation.
- The European Space Agency recently demonstrated MIT researcher Dustin Kendrick's work on a countermeasure skin suit on an ISS mission.

- Eric Stern, a researcher from the University of Minnesota, developed a revolutionary and unique means of characterizing internal fluid dynamic and thermochemical processes of porous TPS materials.

NASA Innovative Advanced Concepts

The NASA Innovative Advanced Concepts (NIAC) made 15 Phase I and seven Phase II awards across industry, academia, and NASA Centers while completing 12 Phase I and six Phase II studies. One example of a NIAC success story in FY 2015 is 2013 Fellow Dr. Chris Walker, a professor at the University of Arizona. Walker's research in creating a pressurized balloon mirror inside a weather balloon has enabled astrophysics above 99 percent of the atmosphere without the cost of a spacecraft. This project has received multiple follow-on grants and contracts from NASA and the Department of Defense.

Centennial Challenges

The Centennial Challenges Program conducted a record four competition events in FY 2015 and awarded prize money in each, a first for the program. Worcester Polytechnic Institute hosted the fourth year of the Sample Return Robot Challenge in June. The purpose is to demonstrate robots that can locate and retrieve geologic samples from a wide and varied terrain without human control or terrestrial navigation aids. West Virginia University met two of the Level 2 requirements and received a $100,000 award. Fifteen teams competed in the first year of the Mars Ascent Vehicle Challenge. Teams are challenged to develop an autonomous robotic system that can load a sample into a rocket, launch to a predetermined altitude, and safely return the sample container to Earth. North Carolina State University won first place ($25,000), and Tarleton State University won second ($15,000). The program conducted the first Ground Tournament (GT-1) of the Cube Quest Challenge in August. The purpose of the challenge is to design, build, and launch flight-qualified, small satellites capable of advanced operations near and beyond the moon. Thirteen teams participated in GT-1; five teams won $20,000 each. The program conducted the 3-D Printed Habitat

Challenge in September. The purpose of the challenge is to advance the additive construction technology to create sustainable housing on Earth and beyond. This challenge received over 165 entries and awarded the top three entries at the Maker Faire in New York in September. The first-place winner, Team Space Exploration Architecture and Clouds Architecture Office, received $25,000. The second-place winner, Team Gamma (Foster + Partners), received $15,000. Team LavaHive (ESA European Astronaut Centre and LIQUIFER Systems Group) won third place.

This page is intentionally left blank.

Department of Defense

DOD

Aeronautics Activities

Fixed-Wing Aircraft

The Department of Defense (DOD) continued flight test evaluations of the three F-35 Joint Strike Fighter (JSF) variants: the F-35A conventional takeoff and landing, the F-35B short takeoff and vertical landing, and the F-35C aircraft carrier variant. The first separation test of a Guided Bomb Unit (GBU)–39 Small Diameter Bomb (SDB) from an F-35A occurred on October 21, 2014. Block 3F flight testing began on July 10, 2015. Also, DOD completed Block 2B weapons testing, Block 3i weapons testing, and 25-millimeter internal gun firing tests (ground only) during FY 2015. The Marine Corps declared Initial Operational Capability (IOC) for the F-35B on July 31, 2015.

The Navy's F-35C carrier aircraft completed its second sea trials and the fifth sea-based test event aboard the USS George Washington in October of 2015. The Navy successfully completed three test events aboard L-Class aircraft carriers by the F-35B and two by the F-35C. The F-35B and F-35C represent a new frontier for naval aviation, integrating a stealth aircraft with an aircraft carrier.

The international community has shown strong support for the F-35. The Final Assembly and Check Out (FACO) facility in Cameri, Italy, rolled out its first two aircraft during 2015, resulting in Italy's and Norway's first F-35As.

During FY 2015, F-15C/E Eagles served in the U.S. Central Command theater of operations and deployed multiple times to the U.S. European Command as part of theater security packages against Russian aggression in Eastern Europe.

The Air Force worked toward a major modernization surge on the F-15 Eagle air superiority and global precision attack weapon system with upgrades including the operational flight program, the production and installation of Modern Advanced Electronically Scanned Array Radars, the Advanced Display Core Processer II, and the Acquisition Category I Eagle Passive/Active Warning Survivability System. The Air Force also conducted in-depth structural fatigue life testing to determine what modifications are required to extend the service of the platform into the 2040s. These hardware and software programs set the foundation for the F-15 Eagle weapon system to serve as an advanced, fourth-generation fighter augmenting the fifth-generation fleet.

The Air Force continued work on the KC-46 aerial tanker and C-5 cargo aircraft. The KC-46 program initiated the build of four Engineering and Manufacturing Development aircraft in 2014 and began flight tests in 2015. The first KC-46 test aircraft took off on its first flight on September 25, 2015, at Paine Field in Washington State. Additionally, the Air Force secured approval to begin pre-engineering, manufacturing, and development work on the recapitalization effort for the Presidential Aircraft, also known as Air Force One. In January, the Air Force selected the Boeing 747-8 as the replacement platform for the VC-25. The Air Force completed the Reliability Enhancement and Re-engining Program (RERP) modification on the first of two C-5C aircraft used to transport outsized NASA cargo. Upon completion of RERP, the Air Force plans to redesignate 49 C-5Bs, one C-5A, and two C-5Cs as C-5Ms, indicating increased range, payload, takeoff thrust, climb performance, and fuel efficiency, as well as an extended service life until at least 2040.

The Persistent Close Air Support (PCAS) program focuses on significantly increasing continuous close air support (CAS) capabilities that enable enhanced manned/unmanned attack platform strike capabilities; create next-generation graphical user interfaces, digital guidance, and control; support advanced munitions; and reduce collateral damage and potential fratricide for coordinated attacks against multiple, simultaneous targets. In May 2015, PCAS conducted 50 flight sorties exercising the PCAS system end to end, with ten successful live-fire weapons employments. PCAS will improve U.S. ground forces operations and speed of attack by allowing the Joint Tactical Air Controller the ability to rapidly engage multiple moving targets simultaneously within the area of operation.

The Air Force Research Laboratory (AFRL), through work with NASA on the joint Environmentally Responsible Aviation project, conducted flight tests to demonstrate Adaptive Compliant Trailing Edge flaps. AFRL also fabricated and tested a variable camber compliant wing. A variable camber compliant wing is a technology in which a single carbon-fiber composite skin enables active changes to the wing camber.

Rotorcraft

The Air Force Institute of Technology (AFIT) conducted experiments involving mistuning in a turbine rotor, which occurs due to geometric imperfections in the blade. AFIT conducted experiments to determine the force response and mistuning patterns for each rotor, resulting in a characterization of each rotor's mistuning as a predictor of high-cycle fatigue.

In September 2015, the Vertical Take-Off and Landing (VTOL) Technology Demonstrator program successfully completed subscale demonstrator development activities, ground tests, and preflight checks. Key design features included a first-ever all-electric, tilt-wing, distributed ducted-fan propulsion system with the incorporation of flightworthy three-dimensional printed parts. The VTOL Technology Demonstrator program develops technologies to enable revolutionary improvements in heavier-than-air VTOL air vehicle capabilities through the development of subsystems, aircraft configurations, and design integration. The program plans to build and flight test an unmanned aircraft weighing approximately 12,000 pounds, capable of sustained speeds in excess of 300 knots while enhancing hover and cruise efficiencies.

The Army continued developing the Joint Multi-Role (JMR) Technology Demonstrator (TD), which is expected to transform vertical-lift capabilities across DOD. JMR TD developed two aircraft, one a tilt-rotor and the other a lift-offset compound helicopter. During FY 2015, the Army completed final reviews of the TD's components, subsystems, and system designs; placed orders for long-lead items; and began fabricating components and assembling major subsystems. The Army also moved technologies forward for rotary-wing configurations, including a compound rotorcraft concept with twin-ducted fans and an optimal-speed tilt-rotor

design. Flight demonstrations are scheduled to begin in 2017. The TD aircraft are designed to carry 12 troops; hover out of ground effect at an ambient condition of 6,000 feet and 95 degrees Fahrenheit; self-deploy to a range of 2,100 nautical miles; and fly at speeds of up to 230 knots.

The Army also developed flight controls, sensors, and cueing required to allow vertical-lift systems to operate safely and effectively in degraded visual environments under the Degraded Visual Environment Mitigation (DVE-M) program. Together with the Air Force and industry partners, the Army completed work in each of the critical DVE-M technology areas: flight controls, sensors, and cueing. The Army completed ground-based testing of eight industry-provided systems at Yuma Proving Ground, Arizona. The tests assessed imaging systems' ability to collect, fuse, and present a discernable image of a populated obstacle field, obscured by blowing dust. The Army plans to further refine and integrate the systems for flight testing in 2016. The Army also demonstrated a new version of Modernized Control Laws for the Black Hawk that further improves flight performance and reduces pilot workload in DVE as part of testing at Moffett Field, California. Finally, the Army completed the first of a series of cueing experiments to investigate the contributions of visual, aural, and haptic cueing elements to optimize human performance in DVE.

In software development, the Army released an update of its Helios (v.5.3) modeling and simulation software for rotorcraft aeromechanics. In addition to the previously existing capabilities for high-fidelity simulations of full-vehicle rotor and fuselage combinations, Helios v.5.3 added an option to bring the NASA computational fluid dynamics OVERset grid FLOW solver (OVERFLOW) into the Helios framework. This addition of OVERFLOW to Helios allowed for faster and more accurate simulations of rotor blade aerodynamics.

In collaboration with the Israeli Ministry of Defense, the Army executed a flight test to assess TRIO, a stackable, three-section air-delivery technology. The TRIO effort is intended to develop a rugged, low-cost multi-section stackable helicopter external load that can deliver as much as 6,000 pounds of materials at high speeds (in excess of 100 knots) utilizing an automatic release mechanism to deposit supplies at as many as three locations in a single sortie. The testing to date focused primarily on evaluation of the automatic release mechanism in the bottom and middle boxes ballasted to a heavy configuration.

Hypersonics

The Office of the Secretary of Defense (OSD) Conventional Prompt Global Strike (CPGS) effort conducted technology development during FY 2015 for risk reduction in several key areas, including aerodynamics, thermo-structural physics, testing, and evaluation. OSD employed five U.S. hypersonic wind tunnel facilities to generate high-fidelity aerodynamic and aerothermal databases that can be used to develop trajectories, guidance and control algorithms, and a thermal protection system for candidate vehicles. The synergy between ground tests and modeling and simulation (M&S) through post-test analyses led to updating state-of-the-art M&S models. The CPGS effort held a Preliminary Design Review for an upcoming hypersonic flight experiment that will serve as a demonstration and evaluation of the latest technologies.

Unmanned Aircraft Systems

The U.S. Marine Corps began fielding the RQ-21 Blackjack to the first operational squadron in FY 2015. In addition to the Marine Corps's currently fielded RQ-7Bs, the Marine Corps began fielding the RQ-21 Blackjack to squadrons to support Marine Expeditionary Units (MEU) afloat, Marine Special Operations Command (MARSOC) units, and other Marine Corps regimental-sized units.

The United States Navy is executing the MQ-4C Triton Program to develop persistent maritime and littoral intelligence, surveillance, and reconnaissance capabilities for the fleet to enhance situational awareness and reduce sensor-to-shooter kill-chain timelines. The Navy began Integrated Functional Capability flight testing in April 2015 in preparation for an operational assessment planned for late 2015. The Navy has MQ-4C Triton System Demonstration Test Article assets in production and conducted an Executive Production Readiness Review in June 2015 to confirm production readiness. The Navy also awarded a PDR contract for the Multi-Intelligence Sensor Upgrade in September 2015.

The United States Air Force is executing the RQ-4 Global Hawk Program to provide continuous, high-altitude, long-endurance, all-weather, day/night wide area surveillance and reconnaissance capability. The Global Hawk core program

is in the final portion of the aircraft production phase, with an expected completion in FY 2017. In 2015, the program shifted focus to planning and executing a series of modernization efforts including Sensor Integration, Ground Segment Modification, Communication System Modification, Operational Flight Program, and Ice Protection.

An Omega K-707 tanker aircraft completed the first-ever fully autonomous aerial refueling operation of the Navy's X-47B carrier-based unmanned combat aircraft demonstrator in April 2015.

Airborne Weapons Systems and Missiles

In July 2015, a Standard Missile–6 (SM-6) Dual 1, fired from the USS John Paul Jones, intercepted a short-range ballistic missile launched from the Pacific Missile Range Facility in Kauai, Hawaii. This test demonstrated DOD's capability to intercept low-flying cruise missiles or space-hugging ballistic missiles as they neared their terminal points of impact from a sea-based platform. The test also demonstrated the new SM-6 variant's ability to destroy a ballistic missile in the last moments of flight. DOD derived the SM-6 Dual 1 from the existing SM-6s built to target cruise missiles. The Dual 1 joins the U.S. Army's Patriot missiles as the only U.S. interceptors capable of defending against both cruise and ballistic missiles.

The Air Force Ground Based Strategic Deterrent (GBSD) team's accomplishments during FY 2015 included working with the Navy to understand the level of common work between intercontinental ballistic missiles (ICBM) and submarine-launched ballistic missiles and, recently, receiving the Air Force's Requirements Oversight Committee approval of the GBSD program's draft Capabilities Development Document (CDD). All these activities supported a decision to enter the Technology Maturation and Risk Reduction phase of the project in FY 2016. The CDD provides requirement threshold and objective values to take forward into the post–Milestone-A Technology Maturation and Risk Reduction (TMRR) acquisition phase as the program evaluates and matures technologies for a future ICBM system to replace Minuteman-III in the late 2020s.

Space Activities

Launch and Range Operations and Spacelift Developments

The Evolved Expendable Launch Vehicle (EELV) program continued to successfully place satellites into orbit during FY 2015. United Launch Alliance continued its record of success with ten launches. These launches included eight national security space (NSS) missions, summarized below (date: launch vehicle, configuration, payload):

- October 29, 2014: Atlas 5 (401), Global Positioning System (GPS)–IIF-8
- December 12, 2014: Atlas 5 (541), National Reconnaissance Office Launch–35
- January 21, 2015: Atlas 5 (551), Mobile User Objective System (MUOS)–3
- March 25, 2015: Delta 4 Medium+ (4,2), GPS-IIF-9
- May 20, 2015: Atlas 5 (501), Air Force Space Command (AFSPC)–5 (X-37B and CubeSats)
- July 15, 2015: Atlas 5 (401), GPS-IIF-10
- July 24, 2015: Delta 4 Medium+ (5, 4), Wideband Global Satellite Communications System–7
- September 2, 2015: Atlas 5 (551), MUOS-4

In addition, the Air Force certified the SpaceX Falcon 9 Launch System for NSS missions in May 2015. The action enabled SpaceX to compete for qualified NSS launch missions as one of two currently certified launch service providers. This milestone culminated a two-year effort by the Air Force to introduce more competition into the EELV program.

Range modernization efforts continued in FY 2015 with the following accomplishments:

1) The Modernization Eastern Range Network (MEN) contract upgraded the Eastern Range mission communications core to address obsolescence issues and improve cyber protection. As part of MEN, the Internet Protocol Companion Contract (IPCC) upgraded the Eastern Range's communications network from Asynchronous Transfer Mode to Internet

Protocol version 4 (Internet Protocol version 6 capable). The IPCC successfully completed its Preliminary Design Review in FY 2015.

2) The Eastern Range Command Destruct Modernization (ERCDM) effort continued to improve upon obsolete range safety and positive control assets used to ensure public safety during space and ballistic missile launches. System design culminated in the combined Preliminary Design Review/Critical Design Review in September 2015. The Western Range Command Destruct Modernization (WRCDM) effort will apply similar upgrades to the Western Range. The Air Force completed WRCDM site surveys and acquisition document development in FY 2015.
3) The Air Force completed Antigua telemetry divestitures and site closure. The effort included demolition, removal, and divestiture of the Antigua telemetry antennas and instruments.

The Hydrocarbon Boost Demonstration subscale pre-burner ground rig test led to the completion of the final design of the full-scale pre-burner, a major component of an advanced liquid-oxygen (LOX)/liquid-kerosene (RP-1) rocket engine. The resulting technologies enable and support domestic space launches. The Hydrocarbon Boost Demonstration pre-burner is being used to support a Space and Missile Systems Center (SMC) and NASA thrust chamber combustion stability demonstration supporting SMC risk-reduction efforts toward a future launch vehicle engine.

Position, Navigation, and Timing

The Global Positioning System program celebrated its 20th anniversary of providing uninterrupted position, navigation, and timing data free of charge to users worldwide. The success of the GPS program is reflected in the total number of GPS receivers produced to date, estimated at four billion worldwide. DOD initially declared the GPS constellation fully operational in July 1995, and two Block IIA satellites from that year remain operational, more than tripling their design life of 7.5 years. To keep the constellation healthy, the program launched three new Block IIF satellites during FY 2015. Besides the legacy signals, these Block IIF satellites will also provide the newest L2C and L5 signals. Daily uploads of the civil

navigation message on L2C and L5 began on December 31, 2014, marking the first new signals available from GPS since initial operations in 1995. The next block of satellites, GPS III, are nearing the completion of their development. The first GPS III satellite began final thermal vacuum testing in the fall of 2015. Finally, the United States and Canada signed a memorandum of understanding this year for Canada to provide 24 search-and-rescue transponders for GPS III, currently scheduled to be available for search-and-rescue operations beginning in 2023.

Satellite Communications

The Advanced Extremely High Frequency (AEHF) is a joint-service satellite communications system that provides global, survivable, secure, protected, and jam-resistant communications for high-priority military ground, sea, and air assets. The Air Force Operational Test and Evaluation Center (AFOTEC) completed dedicated Multi-Service Operational Test and Evaluation (MOT&E) of the AEHF satellite constellation on February 2, 2015, which found the system effective and suitable. DOD declared Initial Operational Capability for AEHF on July 28, 2015, with the three on-orbit AEHF satellites, augmenting the legacy Milstar constellation and providing protected satellite communications for strategic users. Mission Planning Element (MPE) 7.6 arrived in June 2015 for operations by the end of the calendar year. The production of AEHF satellite 4 is nearly complete. DOD awarded the contract for the follow-on MPE Increment 8 on July 1, 2015, to integrate the Family of Advanced Beyond Line of Sight Terminals (FAB-T) and Global Aircrew Strategic Network Terminals and increase system capacity.

The FAB-T program will field nuclear event–survivable terminals capable of communicating with the Milstar and AEHF satellite constellations using jam-resistant, low-probability-of-intercept and low-probability-of-detection waveforms. DOD placed the Command Post Terminal (CPT) variant on contract for initial production in September 2015. CPT will provide command and control of the AEHF constellation and command of nuclear forces by the President.

The first Enhanced Polar System (EPS) payload (on a hosted space vehicle) successfully launched in FY 2015 completed its on-orbit checkout and became ready for operational testing. The second payload is being integrated onto its host

spacecraft with launch expected in FY 2017. The EPS will replace the Interim Polar System, ensuring critical protected communications requirements above 65 degrees north latitude for joint forces.

DOD launched Wideband Global Satellite Communications (SATCOM) (WGS) satellite 7 (WGS-7) on July 23, 2015. WGS-7 is a Block II follow-on version, expected to become operational by December 2015. WGS satellites 8–10 remain in production. WGS is the DOD SATCOM constellation with the highest capacity, declared Full Operational Capability (FOC) with five satellites on May 12, 2014. The DOD has a total of ten satellites either on orbit or in production. The WGS system provides up to 2.6 gigabits per second per satellite (over 11 gigabits per second worldwide) to support various missions of the Unified Combatant Commanders (UCCs), military services, other DOD agencies, and international partners (Australia, Canada, Denmark, the Netherlands, New Zealand, and Luxembourg).

The Mobile User Objective System (MUOS) provides narrowband communications using two separate payloads: a legacy Ultra-High Frequency (UHF) capability and the new Wideband Code Division Multiple Access (WCDMA) payload. DOD launched MUOS satellite 3 on January 21, 2015, and MUOS satellite 4 on September 2, 2015. MUOS satellite 5 is completing production and scheduled to launch in May 2016. MUOS Waveform v3.1.4 Increment 1 arrived on July 30, 2015, to support MOT&E-2 in October 2015.

Indications and Warning

The Space Based Infrared System (SBIRS) provides missile warning and supports missile defense, technical intelligence, and battlespace awareness mission areas. The nominal constellation consists of four Geosynchronous Earth Orbit (GEO) satellites, two hosted sensors in Highly Elliptical Orbit (HEO), and associated ground elements. The SBIRS GEO-1 and GEO-2 satellites have been certified for operations since 2013, and the SBIRS HEO-3 payload made orbit in April 2015. The HEO-4 payload shipped from the contractor for integration with the host satellite in May 2015. The GEO-3 satellite completed production in July 2015 and went into storage, while the GEO-4 satellite continued production with no major

issues. In June 2015, the Air Force signed a no-cost change to a fixed-price contract to modernize the GEO-5/GEO-6 satellite bus in production. Additionally, the Air Force continued development of the ground segment with a goal of consolidating the operations into a single source for processing and dissemination of fused Overhead Persistent Infrared (OPIR) data.

Satellite Control and Space Situational Awareness

In January 2015, the Joint Space Operations Center (JSpOC) Mission System (JMS) completed the integration of Service Pack 9 (SP-9), transitioning the authoritative catalog of space objects from the legacy database to JMS. SP-9 also enabled significant new capabilities, including catalog growth to 1,000,000 objects with future scalability; "all vs. all" conjunction assessment; automated, continuously updated, high-accuracy orbit determination; and maneuver detection. JMS is an agile information technology development program delivering capabilities in a series of increments. Increment 1 has been in continuous use since November 2012 and has supported multiple high-profile events since inception. In 2015, the contractor completed Increment 2 Service Pack 7 development and delivered the associated infrastructure hardware to the JSpOC.

Groundbreaking for Space Fence Increment 1 occurred on Kwajalein Atoll, Republic of the Marshall Islands, in February 2015. The Air Force expects the Space Fence radar system to improve Space Situational Awareness (SSA) capabilities by providing un-cued surveillance of small objects and satellites in low- and medium-Earth orbit to provide spaceflight safety, early detection and custody of threats, and awareness to satellite operators in the crewed spaceflight regime.

The United States and Australia enjoy an increasingly fruitful relationship in the SSA mission area. The countries completed a C-Band Radar relocation from Ascension Island to Australia in February 2015. Following calibration and operational testing, the system is expected to achieve IOC in FY 2016. The radar will soon become the only U.S. near-Earth dedicated SSA sensor in the Southern Hemisphere. C-band radar provides excellent satellite detection, tracking, and identification capability, along with extremely accurate space object positional data and the ability to increase maneuver detection and conjunction assessment

capabilities. Efforts began to operationalize the Space Surveillance Telescope (SST) located at White Sands Missile Range, New Mexico, prior to its relocation to Harold E. Holt Naval Communication Station in Exmouth, Western Australia. SST technology enables faster discovery and tracking of previously unseen, hard-to-find small objects in geosynchronous orbits. The system leverages multiple technology improvements to provide orders-of-magnitude enhancements in search rate and sensitivity over existing ground telescopes. Australia will operate both the C-Band Radar and SST systems in partnership with the United States.

The Air Force successfully completed the Preliminary Design Review for Phase II of the Ground-based Electro Optical Deep Space Surveillance (GEODSS) Service Life Extension Program (SLEP) in August 2015. Phase II replaces aging and unsupportable mission-critical subsystems in the Data Processing Group with modern, sustainable components to allow the system to continue providing time-critical deep space tracking information. In addition, the Eglin Radar completed a SLEP of its Control and Signal Processor in June 2015 to extend the life of the phased array radar dedicated to finding and tracking near-Earth and deep space objects.

Other Space Developments

AFRL is working to integrate hardware into spacecraft structure to monitor the health of the structural elements. During 2015, AFRL incorporated piezoelectric beamforming elements and precision tri-axial accelerometers into the flight hardware of the Space Test Program-H5 payload for a yearlong test on the International Space Station.

AFRL also adapted principal component analysis compression theories for use in quantitative analysis when it is important to preserve critical space signals and features within the data while also allowing for higher compression ratios. AFRL submitted a provisional patent for this compression technique.

The third flight of the X-37B or Orbital Test Vehicle (OTV-3) landed at Vandenberg Air Force Base, California, on October 17, 2014, completing a record-setting 675 days in orbit. OTV-4 launched on May 20, 2015, to test the performance of an experimental propulsion system (Hall Current Thruster), jointly developed by AFRL and the Space and Missile Systems Center, as well as a series of advanced

material plates developed by NASA. The X-37B is an experimental test program to demonstrate technologies for a reliable, reusable, uncrewed space test platform.

The X-37B has proven to be a powerful test bed for a new Hall Current Thruster (HCT) design. AFRL designed, built, and ground-tested a modified version of the Hall Thruster currently in use on the AEHF communications satellite. AFRL launched the new thruster on AFSPC-5 on May 20, 2015, only three years after the initial concept. Onboard measurements indicated performance of the new Hall Thruster design to be superior to the current system. The new design has been accepted into the product line as the first of the second generation of 5-kilowatt Hall Thrusters. The program continues to collect data both on board and from ground observations to refine environment/thruster coupled models.

Officials from the 50th Space Wing completed their operations review of the Defense Meteorological Satellite Program Flight 13, which permanently shut down on February 3, 2015, precipitating a debris-causing event. The review determined that no actions could have been taken to prevent the incident. The mission is operated by the National Oceanic and Atmospheric Administration on behalf of the U.S. Air Force.

The Vector Joint Capability Technology Demonstration (JCTD) proved the military utility of nanosatellites for an advanced communications capability. The Navy's Program Executive Office for Space Systems continued development of the Integrated Communications Extension Capability (ICE-Cap) nanosatellite to augment UHF communications at the North Pole. A study by the Space and Naval Warfare Systems Command (SPAWAR), the Naval Research Laboratory (NRL), and the Program Executive Office for Space Systems found nanosatellites to be a cost-effective augmentation for radar altimetry missions, such as Jason-3.

The Counter Communications System (CCS) provides expeditionary, deployable, reversible counter-space effects applicable across the full spectrum of conflict. The CCS denies adversary satellite communications in an area of conflict to include command and control, early warning, and propaganda dissemination. The pre-planned product improvements, which transition the system to Increment 10.2, remain on track and are progressing well.

In 2015, the Operationally Responsive Space (ORS) Office continued to support the on-orbit operations of the ORS-1 satellite, launched in June 2011 from NASA's

Wallops Flight Facility, Virginia. Although designed with a life of two years, ORS-1 continued to support U.S. Central Command throughout FY 2015. Additionally, ORS continued to directly support Joint Force Commander needs with the development of ORS-5 to satisfy a U.S. Strategic Command need. The ORS-5 satellite will demonstrate SSA (wide-area search capability) of the geosynchronous orbit belt with a small satellite in low-Earth orbit, provide risk reduction to the Space Based Space Surveillance Follow-On (SBSS FO) program, and develop and demonstrate ORS enablers and principles. ORS also continued with ORS-4, developing the small, responsive, low-cost Super-Strypi launch vehicle, planning for a first launch in FY 2016. In April 2015, the Secretary of the Air Force, acting as the DOD Executive Agent for Space, directed the Weather System Gap Filler (WSGF) as the next major ORS project. The WSGF is a combined effort between ORS and the Weather System Follow-On program office to fill an impending gap in space-based weather data collection.

The Space Security and Defense Program (SSDP) is a joint DOD and Office of the Director of National Intelligence (ODNI) organization established to function as the center of excellence for options and strategies (materiel and non-materiel), leading to a more resilient and enduring National Security Space Enterprise. In the past year, the program implemented cyber support to defensive space alternatives and provided assessments and solutions for hosted payloads. Additionally, SSDP conducted a number of analytic efforts focused on enhancing the resilience of space systems in a contested environment. SSDP efforts helped develop and integrate rapid prototyping capabilities for key space mission areas.

A Falcon 9 rocket carrying the Deep Space Climate Observatory (DSCOVR) spacecraft launched from Cape Canaveral Air Force Station on February 11, 2015, for a joint mission between NASA, NOAA, and the U.S. Air Force. The launch delivered the DSCOVR payload on a trajectory to the sun-Earth L1 Lagrange point for a space weather warning mission for NOAA and an Earth science mission for NASA. The Air Force's Rocket Systems Launch Program procured the rocket, the first Falcon 9 mission purchased, and executed the launch under its Orbital/Suborbital Program–3 (OSP-3) contract.

The DOD Space Test Program provides spaceflight opportunities for militarily relevant DOD space research and development payloads, then demonstrates new

technologies in space prior to operational use. In February 2015, the DOD Space Test Program successfully launched an Air Force Research Laboratory experiment called Ionospheric Control, a sounding rocket to study radio-frequency propagation in the ionosphere. Also in February 2015, the Space Test Program deployed a small research satellite from the International Space Station that successfully demonstrated space-to-ground communications over the commercial space-based Globalstar system. Additionally, in September 2015, the Space Test Program successfully launched a Naval Research Laboratory Experiment called Charged Aerosol Release Experiment II, using a sounding rocket to examine the effects of artificially created charged-particulate layers on radar signals.

This page is intentionally left blank.

Federal Aviation Administration

FAA

The Federal Aviation Administration (FAA) saw major milestones completed in its modernization effort, which is moving the national airspace system from ground-based radar to satellite-based navigation, from voice to digital communication, and from point-to-point data to a fully integrated information management system. These initiatives change how we see, navigate, and communicate in the Nation's skies. The Nation's aviation system is a valuable asset that contributes 12 million jobs and $1.5 trillion annually to the U.S. economy. To that end, the agency measured $1.6 billion in benefits to airlines and the traveling public from Next Generation Air Transportation System (NextGen) capabilities already in place.

En Route Automation Modernization

In FY 2015, the FAA completed an air traffic system that will significantly improve air travel through every phase of flight. En Route Automation Modernization (ERAM) uses satellite technology to provide a much more precise picture of air traffic and allow more efficient management of flights from takeoff to touchdown, replacing the former En Route Host plane tracking system, which dated back to the 1960s.

ERAM is part of the multi-year, multibillion-dollar NextGen program to shift air traffic control from ground-based radar to Automatic Dependent Surveillance–Broadcast (via satellite-based Global Positioning System [GPS]) tracking. The system, a crucial foundation for NextGen, is the backbone of operations at the

20 FAA air route traffic control centers (ARTCC). ERAM enabled controllers to track nearly double the number of flights from gate to gate while offering suggestions for the best flight speed and path to avoid weather and congestion. ERAM increased the number of aircraft tracked by ARTCCs from 1,100 to 1,900. This precision also enabled controllers to safely space planes three miles apart, rather than the previous five miles.

The first ERAM system went online at Salt Lake City Center in March 2012, and the FAA completed the final installation in March 2015 at the New York Center. The FAA designed ERAM to be the operating platform for other NextGen technologies, including Performance Based Navigation, Automatic Dependent Surveillance–Broadcast, and Data Communications (Data Comm).

Performance Based Navigation

ERAM encourages the use of Performance Based Navigation (PBN) procedures that enable controllers and flight crews to know exactly when to reduce the thrust on aircraft, allowing them to descend from cruising altitude to the runway with the engines set at rear idle power, saving on flying time and fuel consumption. As of FY 2015, the FAA has established thousands more routes and procedures based on PBN satellite technology to make the flow of air traffic more efficient at 463 airports, from the largest, busiest hubs to general aviation airfields. For example, Atlanta Hartsfield Airport reported flights to be 48 percent faster from the gate to departure and into en route airspace, and Delta Air Lines showed a savings of $10–$12 million per year at Dallas Fort Worth Airport.

PBN benefits included the following:

- Increased safety through continuous descent procedures.
- Improved airport and airspace access in all weather conditions.
- Reduced delays at airports and in certain dense airspace through the application of new parallel routes; newly enabled ingress/egress points around busy terminal areas; and improved flight re-routing capabilities that make better use of closely spaced procedures and airspace.
- Increased efficiency through more direct routes, especially at lower flight altitudes.

Area Navigation (RNAV) and Required Navigation Performance (RNP) provide environmental benefits through reduced emissions and fuel consumption.

Automatic Dependent Surveillance–Broadcast

The FAA moved steadily toward replacing the old system of ground-based radars to track aircraft with one that relies on satellite-based technologies. ERAM already receives information from aircraft equipped with ADS-B and displays these data on controllers' screens. This technology has made it possible for controllers to provide radar-like separation to aircraft that previously operated in areas where no radar is available, such as the Gulf of Mexico and large parts of Alaska. The FAA expects ADS-B to replace radar as the primary means of tracking aircraft by 2020.

Data Comm

To reduce congestion on radio frequencies, the FAA and the aviation industry continued to develop Data Comm, which will allow controllers and pilots to communicate by direct digital link rather than voice, similar to text messaging. ERAM is already equipped to handle this technology. In FY 2015, the agency continued testing Data Comm at Newark and Memphis and plans to commission Data Comm at new sites in Houston and Salt Lake City in the near future. Data Comm speeds communications, enhances safety by reducing the chance of a read-back error while relaying information, allows controllers to send text instructions to several aircraft at once, and cuts down on travel delays.

Equivalent Lateral Spacing Operations

In FY 2015, Atlanta Hartsfield International became the first airport using Equivalent Lateral Spacing Operations (ELSO). ELSO allows controllers to space routes more closely together and safely clear aircraft for takeoff more efficiently through the use of Performance Based Navigation to fly precise paths with pinpoint accuracy, eliminating the necessity for an extra cushion of airspace around the plane to account for variations in the flightpath. Current air traffic rules require a

15-degree minimum angle between departure routes, but ELSO reduced the minimum to 10 degrees in Atlanta, allowing four flights to depart from the same area where previously only three could be accommodated. This flexibility makes it possible for controllers to clear as many as eight to 12 additional departures every hour, providing a huge benefit for the airport. The FAA plans to expand the procedure to airports in Denver, Detroit, Cleveland, Miami, and Fort Lauderdale.

System Wide Information Management

System Wide Information Management (SWIM) is the digital data delivery pillar of NextGen, providing easy access to a wide range of air traffic control and management information over the Federal Telecommunications Infrastructure (FTI) in a standard data format. In November 2014, the FAA began offering a new SWIM-enabled information capability based on the Traffic Flow Management System (TFMS). The FAA's TFMS monitors demand and capacity information, assesses the impact of system constraints, provides alerts, and helps determine appropriate adjustments. Access to TFMS provides SWIM users with traffic data and flow information including ground delays, ground stops, re-routings, and traffic advisories.

As of March 2015, the FAA implemented the SWIM Surface Visualization Tool (SVT) prototype in 11 sites around the country. The Volpe Center engineered and developed this new Government-owned tool as a Web-based application that gives controllers and traffic managers access to surface data previously unavailable outside of a tower cab. Specifically, the tool provides access to Airport Surface Detection Equipment–Model X (ASDE-X) or the Airport Surface Surveillance Capability System (ASSC) tracking data provided by the SWIM Terminal Data Distribution System (STDDS). STDDS takes airport surface information on aircraft moving on ramps, taxiways, and runways and provides it to airlines, airports, and other interested parties.

SVT improves shared surface situational awareness capabilities in Terminal Radar Approach Controls (TRACON) by allowing controllers to view actual traffic rather than rough estimates based on past activity and plan for changes, such as switching operational runways in response to changing weather conditions. The FAA completed initial SVT implementation in Southern California in April 2014. As

of March 2015, the FAA also implemented SVT at the Los Angeles and New York Air Route Traffic Control Centers; the Northern California, Potomac, Louisville, Chicago, Houston, and New York TRACONs; and the Air Traffic Command System Control Center in Warrenton, Virginia, which manages the flow of air traffic nationwide. This marked the completion of the planned implementation.

Advanced Electronic Flight Strips

The old tried-and-true process of paper flight progress strips, which air traffic controllers in the towers use to track incoming and outgoing flights, has been upgraded to a prototype paperless software program, using emerging NextGen technology, known as the Advanced Electronic Flight Strips (AEFS) system. In FY 2015, the FAA's William J. Hughes Technical Center's Terminal Second Level Engineering team created and designed the prototype AEFS system to demonstrate how providing tower controllers with a single source of collective information increases efficiency while maintaining safety and situational awareness for each controller in the tower cab. Software engineers Guy Monhollen (program lead for AEFS), Joel Knee, and Anthony Kristovich collaborated with air traffic controllers, FAA management, and the National Air Traffic Controllers Association (NATCA) to ensure a user-friendly and adaptable system for each tower's specific needs. AEFS is currently being used at the Phoenix Sky Harbor International Airport traffic control tower.

The FAA plans to replace the prototype AEFS system and the current Electronic Flight Strip Transfer System (EFSTS) with a new flight information system delivered through the Terminal Flight Data Manager (TFDM) program to support the NAS in the long term. The AEFS prototype highlighted the many benefits to come across the NAS with TFDM, including reducing controller heads-down time; increasing controller awareness by allowing more out-the-window scanning time; reducing the time needed to mark strips manually; and increasing accessibility by allowing any controller, traffic management unit, or front-line manager in the cab to access or manipulate information in the system when needed.

Additional information about the FAA Office of NextGen, updates, reports, and other documents can be found online at *http://faa.gov/NextGen*.

Office of Commercial Space Transportation

In 2015, the FAA's Office of Commercial Space Transportation (AST) continued to promote U.S. commercial space transportation, licensing seven orbital commercial space launches: an Orbital Sciences Corporation (now Orbital ATK) Antares launch from the Mid-Atlantic Regional Spaceport (MARS) in Virginia, five SpaceX Falcon 9 launches from Cape Canaveral Air Force Station (CCAFS) in Florida, and a United Launch Alliance (ULA) Delta IV Heavy launch from CCAFS. AST also licensed a pad abort test of a SpaceX Dragon crewed vehicle. AST provided permits for two suborbital commercial space launches: a Scaled Composites SpaceShipTwo launch from Mojave Air and Space Port in California and a Blue Origin New Shepard launch from the company's test site in western Texas.

Two AST licensed orbital launches ended in failure. In October 2014, the Antares vehicle exploded immediately after liftoff, causing significant property damage to the MARS site. In June 2015, a Falcon 9 vehicle carrying cargo to the International Space Station (ISS) failed during ascent, causing no property damage beyond that of the Falcon 9 and its cargo. In both instances, no fatalities or injuries occurred.

One permitted launch, that of the SpaceShipTwo vehicle, ended in failure about 13 seconds after release from the WhiteKnightTwo carrier vehicle during a powered test flight. This accident resulted in two crew casualties (one fatality and one injury) with no other fatalities or injuries. AST safety inspectors remained on-site for each launch, ensuring public safety by verifying operator compliance with FAA regulations and with the terms and conditions of their specific licenses or permits.

AST did not issue any new launch licenses during FY 2015. AST granted one reentry license to SpaceX for reentry of its Dragon Cargo capsule in support of the Spx-7 mission to the ISS and one launch license renewal to Orbital ATK for Minotaur-C launches from Vandenberg Air Force Base (VAFB). AST granted a launch site operator license to the Houston Airport System in Texas, bringing the total number of AST licensed launch and reentry sites to ten. AST renewed launch site operator licenses for Space Florida for operations at CCAFS, Jacksonville Aviation Authority for operation of Cecil Field Spaceport, and Alaska Aerospace Corporation for operation of Pacific Spaceport Complex Alaska.

AST issued a new experimental permit to SpaceX for flights of its Dragonfly Reusable Launch Vehicle at the company's McGregor Test Site in Texas. AST also renewed Blue Origin's experimental permit authorizing it to continue tests of the New Shepard vehicle at the company's West Texas site. AST did not issue any new safety approvals during the fiscal year but did renew a safety approval for the National Aerospace Training and Research Center based in Pennsylvania.

AST inspectors conducted 218 safety inspections on 116 different types of FAA-regulated activities. AST conducted inspections at various locations including Burns Flat, Oklahoma; Cape Canaveral Air Force Station, Florida; Decatur, Alabama; Pacific Spaceport Complex Alaska, Alaska; McGregor Test Site, Texas; and Mid-Atlantic Regional Spaceport, Virginia.

In FY 2015, AST issued its final Environmental Impact Assessment (EIS), Finding of No Significant Impact, and Record of Decision (ROD) for the Houston Spaceport in Harris County, Texas. AST subsequently issued the Launch Site Operator license for Houston Spaceport in June.

Also in 2015, the FAA continued support of its Center of Excellence for Commercial Space Transportation (COE CST), which enables the FAA to work with universities and their industry partners to conduct research in environmental and aviation safety, as well as other activities, to ensure a safe and efficient air transportation system. The COE CST, working with nine member universities, provides grants with a one-to-one matching requirement (one non-Federal dollar for every Federal dollar granted) in four distinct research areas: space traffic management and operations; space transportation operations, technologies, and payloads; human spaceflight; and space transportation industry viability.

In 2015, AST also conducted a payload review of inflatable lunar habitats being developed by Bigelow Aerospace to address the uncertain regulatory environment as it relates to commercial activity on the moon. Though not a Government endorsement of property rights on celestial bodies, AST used its launch licensing authority to ensure that Bigelow could carry out its activities on the moon safely and without interference from other companies licensed by the FAA. This action was seen as a small step toward supporting commercial activities beyond low-Earth orbit.

In FY 2015, the FAA did not solicit any new Space Transportation Infrastructure Matching (STIM) grant proposals or make new awards.

Additional information about the FAA Office of Commercial Space Transportation, regulations, reports, and other documents can be found online at *http://faa.gov/go/space*.

Department of Commerce

DOC

During FY 2015, the Department of Commerce (DOC) continued to participate in the national management of the Global Positioning System (GPS) as a member of the National Executive Committee for Space-Based Positioning, Navigation, and Timing, the senior body that advises and coordinates Federal agencies on GPS matters. At the committee's request, DOC led an interagency effort to estimate the economic benefits of GPS. The initial estimate found that GPS technology enabled $55.7 billion of U.S. economic benefits across a limed set of industries in 2013. In addition to participating in the committee's meetings and activities, DOC continued to host the committee's offices and its *https://www.gps.gov* Web site. The site remained a top hit in Web searches for "GPS", serving over 1.3 million users in FY 2015.

DOC participated in White House–led consultations with Japan to discuss space cooperation, including satellite navigation, Earth observation, and export control reform. DOC finalized the text of a formal license allowing the Japan Aerospace Exploration Agency to continue operating its existing Quasi-Zenith Satellite System monitoring station at NOAA's Weather Forecast Office in Guam. DOC cochaired a meeting of a U.S.-European working group on trade issues affecting GPS and Europe's Galileo satellite navigation system. DOC also participated in meetings of the International Committee on Global Navigation Satellite Systems to discuss market access issues affecting U.S. industry.

In September 2015, NOAA released a draft of its first Commercial Space Policy for public comment. The policy establishes broad principles for the use of commercial space-based approaches for NOAA's observational requirements and may potentially open a pathway for new industry to join the space-based Earth

observation process. Earlier in the year, NOAA also held the first in a series of public workshops to discuss the NOAA satellite data requirements process and how the agency can and should engage with the commercial sector to fulfill such requirements.

National Oceanic and Atmospheric Administration

In FY 2015, the National Oceanic and Atmospheric Administration's (NOAA) satellites remained as critical as ever, monitoring the severe drought and wildfires in the West, flooding outbreaks in Oklahoma and Texas, a brutal winter season in Boston, and the culmination of Earth's warmest year on record. Twenty-four-hour global coverage from NOAA's satellites provides scientists and managers with a continuous stream of information used in preparation for events impacting our climate, weather, and oceans. NOAA manages and operates four primary types of environmental satellites: geostationary environmental satellites, polar-orbiting environmental satellites, ocean altimetry satellites, and space weather satellites.

NOAA's Geostationary Satellites

Geostationary Operational Environmental Satellite (GOES) satellites continuously monitor the Western Hemisphere by circling Earth in a geosynchronous orbit 22,000 miles above the equator, meaning they remain over one position on the surface by orbiting at a speed matching that of Earth's rotation. GOES imagery and data help meteorologists with forecasting weather in the short term, tracking severe storms, and estimating precipitation for issuing winter storm warnings and spring snow-melt advisories. In FY 2015, GOES-15 flew at 135° west longitude and served as "GOES-West," while GOES-13 flew at 75° west and served as "GOES-East."

NOAA's Polar-Orbiting Satellites

NOAA's primary polar-orbiting environmental satellites, Polar-orbiting Operational Environmental Satellites (POES) and Suomi National Polar-orbiting Partnership (Suomi NPP), orbit Earth at an altitude of approximately 517 miles,

passing close to both poles and providing complete views of weather around the world. POES provides full global coverage with advanced sensors for weather and climate data, collecting information on temperature, atmospheric conditions, wind speed, cloud formation, and drought conditions over the entire Earth. All major numerical weather prediction (NWP) centers around the world use this information as the basis of nearly every medium-term weather forecast.

The Suomi NPP satellite remained NOAA's primary operational polar-orbiting satellite. Suomi NPP is a joint NOAA-NASA mission and serves as a bridge between NOAA's current fleet of polar-orbiting satellites and the upcoming next-generation Joint Polar Satellite System (JPSS). NOAA-19, NOAA's previous primary operational polar-orbiting satellite, also remains a critical part of NOAA's polar constellation and provides valuable contributions to National Weather Service forecasts.

NOAA's Ocean Altimetry Satellite

NOAA, in partnership with NASA, Centre National d'Études Spatiales (CNES), and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), operates Jason-2, a sea surface topography mission that flies an altimeter to provide high-precision measurements of sea surface height. Jason-2 has been crucial to improvements in weather modeling and tropical storm–intensification forecasting because the temperature of the ocean and ocean currents can change the height of the sea, which can affect the world's weather, including tropical storms. In July 2015, the Jason-2 partners agreed to extend Jason-2 operations until the end of December 2017.

NOAA's Space Weather Mission

NOAA, in partnership with NASA and the USAF, successfully launched the Deep Space Climate Observatory (DSCOVR) mission on February 11, 2015. DSCOVR, NOAA's first operational deep space mission, maintains the Nation's real-time solar wind monitoring capabilities, which are critical to the accuracy and lead time of NOAA's space weather alerts and forecasts. Without timely and accurate warnings, space weather events, like the geomagnetic storms caused

by changes in solar wind, have the potential to disrupt nearly every major public infrastructure system, including power grids, telecommunications, aviation, and GPS. Once fully calibrated and validated, DSCOVR will succeed NASA's Advanced Composition Explorer's (ACE) role in supporting solar wind alerts and warnings from the L1 orbit, the neutral gravity point between Earth and the sun approximately one million miles from Earth.

NOAA's Additional Space-Based Capabilities

In addition to those four main types of environmental satellites, NOAA, together with international partners, flew two other types of instruments on some of its satellites.

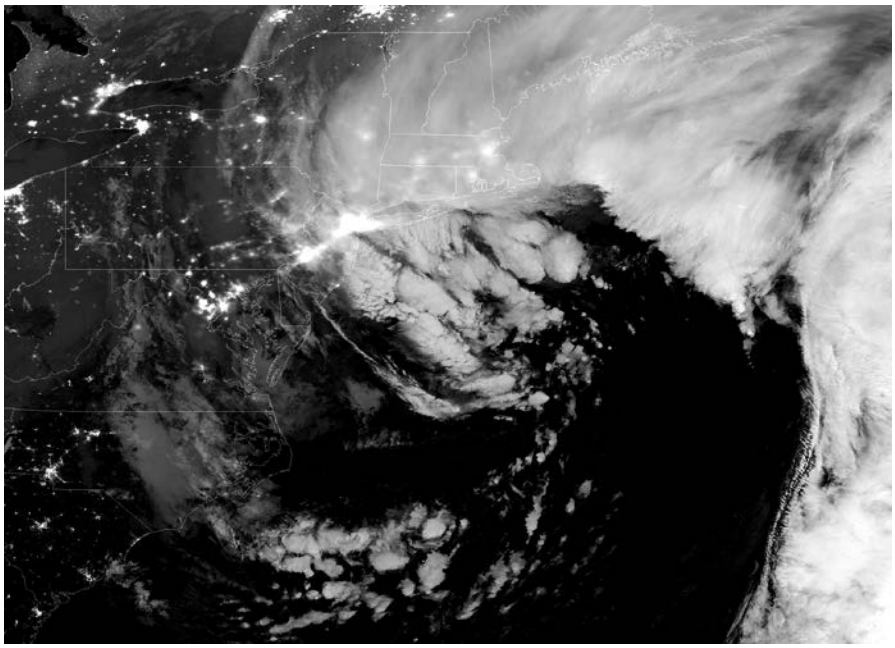
Argos is a data collection and location relay system administered under an agreement between NOAA and CNES initiated in 1974. CNES provides sensors that collect a wide variety of in situ measurements, including data on atmospheric pressure, sea temperature, ocean-current velocity, animal migration patterns, and river water levels.

The Search and Rescue Satellite-Aided Tracking system (COSPAS-SARSAT) is an international system that uses satellites to locate emergency beacons carried by ships, aircraft, or individuals and communicate location information to search-and-rescue authorities. The system has rescued over 39,000 people worldwide since 1982. NOAA provides space on its polar-orbiting satellites for the French processor and Canadian receiver.

National Institute of Standards and Technology

In FY 2015, the National Institute of Standards and Technology (NIST) continued to provide Federal agencies and the aerospace industry with the research, guidance, standards, products, and services needed to advance the President's aeronautics and space agenda. These wide-ranging outputs fall into four main categories: 1) calibrations and measurements for the aerospace industry, 2) calibrations of satellite sensors, 3) development of astronomical and satellite sensors, and 4) support of manufacturing technology.

As the storm moves offshore and the skies clear over the northeastern United States, the extent of snowfall from the blizzard is shown in this image from the Suomi NPP satellite imagery, taken on January 28, 2015, at 1:50 EST. Portions of Suffolk County, New York, and parts of eastern and southern New England, including areas in and around Portland, Maine; Boston, Massachusetts; and Providence, Rhode Island, received more than 20 inches of snowfall. Auburn, Hudson, and Lunenburg, Massachusetts, reported up to 36 inches of snow. (NOAA)



A combination of the day-night band and high-resolution infrared imagery from the Suomi NPP satellite shows the historic blizzard near peak intensity as it moves over the region covering New York and the Boston Metropolitan area at 1:45 a.m. EST on January 27, 2015. The high cloud tops associated with the most intense parts of the storm blurred the nighttime lights in the region. (NOAA)

NIST Calibrations and Measurements for the Aerospace Industry

Traceable NIST measurements (mass, force, vibration, acoustics, electricity, thermometry, humidity, flow, pressure, viscosity, fluid density, radiometry, and length) are essential for aircraft manufacturing. For instance, every tool used in Boeing's 787 airplane assembly process has been calibrated in Boeing's metrology laboratories with direct traceability to NIST. Other direct applications of NIST measurements this fiscal year included the use of NIST-calibrated weights to support wind tunnel applications; weighing airplanes; and the measurement of torque, pressure, and force. NIST worked with the Department of Defense and Boeing on the applicability of laser-scanning technology for the dimensional measurement of aircraft components. The work included developing calibration methodologies and facilities for laser-scanner systems and national and international standardization of their measurement accuracy.

NIST provided air-speed measurement calibrations of anemometers used at airports, on aircraft, and in wind tunnels. The hydrocarbon-liquid calibration service tested flow meters used to measure jet fuel, such as turbine meters used to evaluate jet engine performance on test stands.

NIST has an ongoing engagement with the Boeing Company to identify technical issues and to define requirements for industrial wireless networking, cybersecurity in manufacturing environments, and prognostics and health management for manufacturing systems.

NIST contributed to workshops with the Federal Aviation Administration, the Department of Defense, NASA, and aerospace industry representatives, including Honeywell Aerospace, Lockheed Martin, and Northrop Grumman, to identify proposed approaches for the qualification and certification of additive manufacturing materials, processes, and parts for use in load-bearing and mission-critical applications.

NIST collaborated with members of the Additive Manufacturing Consortium (AMC), including aerospace companies General Electric Aviation, Rolls-Royce, and United Technologies Aerospace, to conduct round-robin testing and determine the mechanical properties of Inconel 625 parts made using the direct metal laser sintering process. NIST also collaborated with the U.S. Department of Energy to

develop measurement methods and experimental data to improve the machining of high-performance materials, such as titanium and nickel-based alloys used for aerospace applications.

During FY 2015, NIST collaborated with NASA Glenn Research Center (GRC) on spacecraft fire detection research. NASA and NIST developed the Smoke Aerosol Measurement Experiment (SAME) with smoke and aerosol measurement instruments to characterize smoke properties from overheated spacecraft materials aboard the International Space Station (ISS). NIST chaired the Fire Safety section of the ISS Combustion Laboratory Workshop sponsored by NASA in FY 2015.

Also in 2015, NIST signed a Memorandum of Understanding (MOU) with NASA to establish cooperation with NASA's MaterialsLab microgravity materials science program. The vision of the MaterialsLab program is to fully utilize the ISS as a national laboratory to conduct microgravity materials science experiments and disseminate data into open science informatics. This partnership with NASA will leverage advanced materials modeling and simulation tools that NIST is developing under its Materials Genome Initiative program.

NIST research addressed safety standards for robotic manipulators and automated guided vehicles (i.e., mobile platforms) and measurement science to enable new capabilities for collaborative robotics, of interest to aerospace manufacturers such as Boeing and Spirit Aerospace.

In FY 2015, several partners in the aerospace community took advantage of the unique capabilities of the NIST Center for Neutron Research to study a number of aerospace challenges:

- Researchers used neutron imaging in continuing studies of alkali metal heat pipes that cool the leading edge of hypersonic aircraft.
- NIST, along with employees of Marshall Space Flight Center (MSFC), used neutron imaging to study the water distribution in proton exchange membrane fuel cell flow fields and gas diffusion layers, as well as collaborating with the NIST imaging group to develop a neutron microscope.
- Researchers from GRC and Michigan Technology University also worked with the neutron imaging facility to develop accurate measurements of thermodynamic parameters in the boiloff of cryogenic liquid propellants critical for understanding long-term microgravity storage of cryogens.

- Researchers from the Air Force Academy collaborated with NIST staff to characterize residual stresses in aluminum alloy samples originating during supersonic particle deposition (SPD). The Cold Spray Process (CSP) that incorporates SPD is a relatively new technology well suited for repair and restoration of nonstructural aircraft components.

NIST Calibrations of Satellite Sensors

NIST provided calibration support for the infrared and optical sensors for two satellite missions under development: the Joint Polar Satellite System (JPSS) and GOES-R. DSCOVR, launched on February 11, 2015, included the NIST Advanced Radiometer (NISTAR), a three-channel radiometer for quantifying the infrared and optical radiation balance for climate science studies.

NIST, in partnership with the University of New Mexico, Harvard University, and the Smithsonian Institution, continued a program to improve the absolute radiometric calibration of stars for applications that include satellite-sensor calibration, dark-energy research, and nighttime aerosol monitoring. NIST made accurate measurements of the amount of light from the moon and sun with the goal of enabling the moon to serve as a calibration source for satellite sensors while they are in space.

NIST continued its collaboration with NOAA on the calibration of the Marine Optical Buoy (MOBY) used in the vicarious calibration of ocean-color measurements provided by satellite sensors. NIST is participating in the MOBY Refresh effort, a multi-year activity to replace aging systems, reduce the risk of instrument failure, and improve measurement variability and uncertainty.

NIST used the Synchrotron Ultraviolet Radiation Facility (SURF) III as a source of soft x-rays and extreme ultraviolet (EUV) light to support the calibration of the EUV Variability Experiment (EVE) aboard NASA's Solar Dynamics Observatory (SDO).

NIST continued the development and deployment of measurement methods to calibrate microwave radiometers as deployed on numerous U.S. operational weather and research satellite assets within NOAA, NASA, and DOD. Working with colleagues at NASA Goddard Space Flight Center (GSFC) through an ongoing

MOU, NIST demonstrated microwave brightness-temperature (radiance) calibrations for the remote sensing bands.

NIST performed calibrations necessary to support the infrared remote sensor used by the Missile Defense Agency.

NIST Development of Astronomical and Satellite Sensors

NIST collaborated with Goddard Space Flight Center to develop photodetectors for space applications. NIST designed and fabricated nanotextured gallium nitride (GaN) and GaN nanowires that serve as raw materials for photocathode detectors. GSFC collaborators activated the material with cesium and packaged the units into complete imaging systems.

NIST collaborated with the Jet Propulsion Laboratory (JPL) on the development of superconducting nanowire single-photon detectors (SNSPDs). NIST characterized various JPL devices and packaged some JPL devices with NIST's self-aligned single-mode optical-fiber packaging scheme. NIST also began joint development with JPL of small arrays of SNSPDs.

NIST developed new detectors based on the voltage-biased superconducting transition-edge sensor (TES). NIST developed integrated TES polarimeters for measuring polarization of the cosmic microwave background (CMB). NIST provided Superconducting Quantum Interference Devices (SQUIDs) and SQUID-based multiplexers to many researchers, both at NASA Centers (Goddard, JPL) and in academia. NIST also used its SQUID expertise to assist GSFC in the development of magnetic micro-calorimeters. NIST continued work on new concepts to achieve on-chip electrical cooling of cryogenic detectors. Recently, NIST demonstrated the first cooling by tunnel junctions of a macroscopic stage that can support user-supplied payloads.

NIST participated in NASA's program support of the European Space Agency's Atomic Clock Ensemble in Space (ACES) program and the Space Optical Clock (SOC) program. NIST continued preparations to host an ACES Microwave Link Ground Terminal and to participate in ACES/Microwave Link time and frequency transfers, as well as international clock comparisons. NIST performed research, development, and evaluation of an ytterbium (Yb) optical lattice clock as a

candidate for the Space Optical Clock program. NIST plans to demonstrate a high-performance optical microcomb that could be used in space for direct comparisons of optical and microwave clocks, in collaboration with scientists at the California Institute of Technology.

NIST helped resolve long-standing discrepancies in the data used to determine properties of hot astronomical objects observed by the Chandra X-ray Observatory and other x-ray missions. NIST collaborated with NASA, the Harvard-Smithsonian Center for Astrophysics, and the Argonne National Laboratory to create atoms in the laboratory in the same extremely hot form as that found in high-energy astrophysical environments.

NIST Manufacturing Extension Partnership

In the first three quarters of FY 2015, NIST Manufacturing Extension Partnership (MEP) centers engaged in 173 projects with 141 individual manufacturing companies designated with an aerospace North American Industry Classification System (NAICS) number (NAICS 3364). The NIST MEP post-project, followup survey of aerospace NAICS companies revealed that MEP services resulted in the creation or retention of 3,350 aerospace jobs, over $122 million in new sales, nearly $155 million in retained sales, over $48 million in new investment, and nearly $29 million in cost savings.

International Trade Administration

Industry and Trade Policy

The Office of Transportation and Machinery (OTM) pursued multiple paths to promote exports of products and services to support the Next Generation Air Transportation System. OTM created and published an online NextGen Solutions Vendors Guide to help foreign customers identify U.S. companies that can provide products that meet the requirements of the International Civil Aviation Organization's (ICAO) Aviation System Block Upgrade (ASBU) technology roadmaps. In 2015, OTM helped to staff the FAA/NextGen booth at the third World

Air Traffic Management Congress in Madrid, Spain, in order to direct potential customers to U.S. exhibitors and non-exhibiting NextGen providers and promote opportunities for foreign delegates to meet with top FAA officials at the booth. OTM also took the opportunity to learn about the specific air-navigation procurement needs of various countries, counsel individual companies on NextGen-related prospects, and recruit participants for the NextGen Solutions Vendors Guide while at the Congress. OTM participated in a number of domestic conferences and exhibitions (such as the 59th Air Traffic Control Association Conference and Exhibition and the 2015 Air Transportation Information Exchange Conference) to discuss the future of the NextGen market with individual companies and learn of their particular regional interests.

OTM personnel also participated in the Unmanned Aircraft Systems Symposium and the Association for Unmanned Vehicle Systems International (AUVSI) Unmanned Systems 2015 Conference to engage with Government, academic, and industry stakeholders within the UAS community, to learn more about the projected market for UAS, to hear about the latest roadmaps for the technology, and to recruit participants for the National Aerospace Foreign Direct Investment Exposition. Additionally, OTM cultivated contacts with various state business development offices at Unmanned Systems 2015, with particular emphasis on the regions not represented by the FAA's six UAS test sites. In addition, OTM contributed to the Global Markets Aerospace and Defense Team's informational sessions at the conference.

OTM continued to support its Memorandum of Agreement (MOA) with Embry-Riddle Aeronautical University (ERAU) to share data and aerospace information and to promote the competitiveness, sustainability, and innovation of the U.S. aerospace manufacturing industry. As part of this effort, ERAU is finalizing a virtual research partnership program in which ERAU-Worldwide students research topics suggested by the International Trade Administration (ITA).

Throughout the year, OTM personnel organized and led four meetings of the Industry Trade Advisory Committee for Aerospace Equipment. The committee provides advice to the Secretary of Commerce and the U.S. Trade Representative on aerospace-related trade policy issues.

ITA continued to support the Office of the U.S. Trade Representative on issues relating to the enforcement of U.S. rights under the World Trade Organization concerning trade in civil aircraft. In particular, OTM has provided support for the ongoing U.S.–European Union (EU) trade dispute over subsidies to manufacturers of large civil aircraft, providing industry expertise in areas relating to changes in the market and actions of the major stakeholders.

ITA's OTM and Office of Finance and Insurance Industries (OFII) continued to participate in the Group on the Sector Understanding on Export Credits for Civil Aircraft (the "Aircraft Sector Understanding" or ASU) at the Organization for Economic Cooperation and Development (OECD). The governments of almost all countries with major aircraft manufacturers have signed the ASU, an annex to the OECD Arrangement on Officially Supported Export Credits, which establishes rules for export credit agencies. The OECD rules aim to ensure that government-provided export financing is not a competitive factor in civil-aircraft sales competitions. A new ASU, which had been completed in early 2011, went into full effect in 2013 and still had observable aftermath in 2015. As a member of the U.S. delegation, ITA helped address the interests of industry during the implementation of the new ASU and monitored and provided advice on how Export-Import (Ex-Im) Bank programs affect the aerospace industry.

ITA and NOAA continued their active participation in the implementation of the current National Space Policies, which include industrial base and competitiveness issues. ITA's OTM actively participated in the implementation of several actions identified in the June 2010 National Space Policy, which revised and updated several aspects of the previous policies. OTM and NOAA continued to ensure that commercial interests would be adequately addressed and that all of the policies' implementation actions would work toward improving U.S. industry's competitiveness, stimulating the American economy, increasing exports, and creating U.S. jobs.

OTM continued to represent commercial remote sensing satellite industry interests within the Remote Sensing Interagency Working Group (RSIWG), led by the State Department. The RSIWG coordinates policy for the export of commercial remote sensing satellite systems and negotiates government-to-government agreements that address the safeguarding of those systems' technology. The RSIWG

consulted with several foreign countries on satellite cooperation and met with industry representatives to understand the impact on related businesses.

In June 2015, ITA organized and supported the Commerce Department's participation in the Paris Air Show and arranged senior-level meetings for the Assistant Secretary for Industry and Analysis with foreign government and industry officials as well as U.S. industry executives. ITA/OTM met with numerous U.S. and foreign government and industry officials to discuss ongoing policy issues impacting the competitiveness of U.S. industry.

Industry and Trade Promotion

ITA conducted a number of trade promotion activities to encourage aviation infrastructure exports in FY 2015. In Brazil and China, ITA held airport roadshows to showcase U.S. technologies and services for airports and air traffic management and provide opportunities for U.S. companies to meet with airport planners. In Indonesia, ITA continued to develop the Aviation Working Group, a public-private initiative to help increase efficiency and safety in Indonesia's aviation system. ITA also hosted Webinars to promote aviation infrastructure opportunities in India as a precursor to the first U.S.-India Strategic and Commerce Dialogue (S&CD) and the November U.S.-India Aviation Summit funded in part by the U.S. Trade and Development Agency.

ITA's Global Aerospace and Defense Team, including Commercial Service (CS) personnel, affected deals with small- and medium-sized companies, as well as larger corporations such as Bell Helicopter, Boeing, General Dynamics, Lockheed Martin, and United Technologies Corporation.

The Global Team participated in over 30 domestic and international aerospace trade events at which team members supported U.S. industry with one-on-one counseling sessions, arranged individualized business-to-business meetings with international business partners, and provided additional export counseling services. ITA trade show support generated hundreds of trade leads for participating companies, allowing them to enter or expand their exports to international markets. These international trade events in FY 2015 included Helitech 2014, Expo Defensa, Airshow China, Aeromart Toulouse, the International Defense

Exhibition and Conference (IDEX), Avalon, Aero India, the Latin America Aerospace and Defence (LAAD) Defence and Security International Exhibition, Aircraft Interiors, the Special Operations Forces Exhibition and Conference (SOFEX), and the Paris Airshow. The Global Team also updated the 2014–15 edition of its Aerospace Resource Guide, which profiles market opportunities in over 40 countries and was well received by industry.

Bureau of Industry and Security

The Bureau of Industry and Security (BIS) continued to support the President's Export Control Reform Efforts as they relate to spacecraft. On July 13, 2015, BIS published a final rule with clarifications and corrections to the current regulations on spacecraft and related items. The changes included in this rule were limited to corrections and clarifications to the regulations and were informed in large part by industry comments received during the first six months of using the new Commerce controls for spacecraft and related items. Overall, feedback on the new rules has been very positive and industry has commented that the rules have transformed the U.S. space industry's ability to compete in foreign markets. As a result of the new regulations, BIS also began participating in the Commercial Satellite Technical Advisory Committee International Space Policy Working Group.

Department of the Interior

DOI

Remotely sensed data and derived information contribute significantly to mission-critical work across the Department of the Interior (DOI). This DOI section highlights a sample of DOI remote sensing applications and illustrates a range of technology, platforms, and specialized sensors employed.

U.S. Geological Survey

The U.S. Geological Survey (USGS) is both a user and a provider of remotely sensed data. The USGS manages the Landsat satellite series and a Web-enabled archive of global Landsat imagery dating back to 1972. The entire Landsat archive became available for download at no charge in December 2008, and by the end of September 2015, the user community had downloaded more than 29 million Landsat scenes. In addition to distributing aerial photography through the National Map, the USGS distributed and archived historical aerial photography, light detection and ranging (lidar) data, declassified imagery, hyperspectral imagery, data collected by Unmanned Aircraft Systems, and imagery from a variety of Government, foreign, and commercial satellites.

Alaska Hyperspectral Remote Sensing Project

The USGS Mineral Resources Program (MRP) used hyperspectral remote sensing at a variety of scales to characterize rocks and soils in selected areas of Alaska using laboratory, field-based, and airborne spectrometers. In July 2015, the USGS collaborated with the University of Alaska Fairbanks (UAF) to utilize their commercially

purchased HySpex sensor in the field to image selected rock outcrops at very fine resolution (5-centimeter pixel size). More information is available online at *http://crustal.cr.usgs.gov/projects/hyperspectral-AK-mineral-deposits/index.html*.

Fires Mapped by Monitoring Trends in Burn Severity Project Approaches 20,000

The Monitoring Trends in Burn Severity (MTBS) project is a collaborative effort between the United States Forest Service (USFS) Remote Sensing Applications Center (RSAC) and the USGS Earth Resources Observation and Science (EROS) Center that uses Landsat data from the archive at USGS EROS to assess burn severity for all known large fires (i.e., greater than or equal to 500 acres in the East, greater than or equal to 1,000 acres in the West) that have occurred on all lands in the United States since 1984. On October 1, 2014, RSAC released 563 fire assessments to the MTBS Web site. This release included 406 fires from 2013 from across the United States and 157 historical fires from Texas. This release brought the total to 18,497 fires that have been mapped across the United States and Puerto Rico. Another release in spring 2015 included over 1,800 historical U.S. Fish and Wildlife Service fires mapped by the USGS EROS over the past two years. The MTBS project provides a basis for local, regional, and national assessment of fire and its short- and long-term effects upon the landscape. More information is available online at *http://www.mtbs.gov/* and *http://eros.usgs.gov/landscape-dynamics/fire-science*.

Fog Frequency Map: Responding to Resource Manager Needs

In coastal California during the hot and dry Mediterranean-like summers, fog and low clouds strongly affect ecosystem dynamics by adding moisture and shading the land surface, thereby reducing plant evapotranspiration stress. However, the presence of fog and low clouds is highly variable from one nearby location to another and also varies from year to year. Public land managers needed maps to show the microclimatic conditions of the landscape to improve restoration and stewardship decisions. USGS scientists compressed nearly 30,000 hourly

images derived by collaborators at the Cooperative Institute for Research in the Atmosphere from the Imager sensor on the Geostationary Operational Environmental Satellite (GOES) for June, July, August, and September over nine summers (1999–2009). Scientists used these data to create detailed maps showing areas with the most stable and highest probability of coastal fog cover and provided climate information to managers to inform their stewardship of the green infrastructure. More information is available online at *http://climate.calcommons.org/datasets/summertime-fog.*

Groundwater Overdraft and Land Subsidence in California

USGS conducted studies in the San Joaquin Valley, in the Coachella Valley, and at the Army's Fort Irwin National Training Center (NTC) to provide information that will allow various Federal, state, and local stakeholders to manage and minimize the impacts of land subsidence on both water-conveyance infrastructures and water deliveries in the two valleys and the aircraft runways at the NTC. The studies use conventional and persistent scatter remote sensing data (Interferometric Synthetic Aperture Radar [IfSAR]) derived from several satellites and GPS data to measure land surface elevation changes, which are then compared to groundwater levels and local geology. In the San Joaquin Valley, the study detected subsidence in nearly the entire valley, including parts of the California Aqueduct, the Delta-Mendota Canal, the San Joaquin River, the Eastside Bypass, the Friant-Kern Canal, and numerous local canals; maximum subsidence rates approached 12 inches (300 millimeters) per year and affected about 5,800 square miles (15,000 square kilometers) by at least 1 inch (25 millimeters) during 2008–10. In the Coachella Valley, the study measured as much as 24 inches (610 millimeters) of subsidence during 1995–2010 and required the realignment of the All-American Canal to mitigate current and potential future subsidence-induced damage. In Fort Irwin's Bicycle Basin, the study measured as much as 16 inches (400 millimeters) of subsidence during 1992–2014 using IfSAR; the differential subsidence across the basin has caused ground fissuring on and near the runway. More information is available online at *http://ca.water.usgs.gov/projects/central-valley/*, *http://ca.water.usgs.gov/projects/coachella.html*, and *http://ca.water.usgs.gov/projects/2010-18.html.*

Landsat Seen as Stunning Return on Public Investment

The National Geospatial Advisory Committee's Landsat Advisory Group—a team composed of commercial, state/local government, and nongovernmental organization (NGO) geospatial information experts—recently released an updated critical review of the value of Landsat data to the U.S. economy. The team of experts outlined 16 decision processes that would be substantially more expensive without an operational Landsat-like program. The team also included nongovernmental science applications where scarce research dollars cannot be wasted on inefficient technologies. Landsat is widely considered to be a crucial national asset, comparable in value to the satellite-based GPS system and the National Weather Service satellites. Ready access to Landsat imagery ensures a reliable and

Landsat Application	Estimated Annual Efficiency Savings
1. USDA Risk Management Agency	Over $100 million
2. U.S. Government Mapping	Over $100 million
3. Monitoring Consumptive Agricultural Water Use	$20–$80 million
4. Monitoring Global Security	$70 million
5. Landsat Support for Fire Management	$28–$30 million
6. Forest Fragmentation Detection	Over $5 million
7. Forest Change Detection	Over $5 million
8. World Agriculture Supply and Demand Estimates	Over $3–$5 million
9. Vineyard Management and Water Conservation	$3–$5 million
10. Flood Mitigation Mapping	Over $4.5 million
11. National Agriculture Commodities Mapping	$1.9 million
12. Waterfowl Habitat Mapping and Monitoring	$1.9 million
13. Coastal Change Analysis Program	$1.5 million
14. Forest Health Monitoring	$1.9 million
15. NGA Global Shoreline	Over $90 million (one time)
16. Wildfire Risk Assessment	$25–$50 million (one time)

This table shows estimated productivity savings from diverse uses of Landsat imagery. These 16 Landsat applications alone produced savings of $350 million to over $436 million per year for Federal and state governments, NGOs, and the private sector.

standardized record of Earth conditions that contributes to the understanding of environmental challenges by citizens, researchers, and decision makers worldwide. More information is available online at *https://www.fgdc.gov/ngac/meetings/december-2014/ngac-landsat-economic-value-paper-2014-update.pdf*.

Modeling Magma Intrusion in Hawaii with IfSAR

The Kilauea volcano on the island of Hawaii has been erupting continuously since 1983, providing volcanologists with unprecedented data on the internal "plumbing" of this shield volcano through which magma (molten rock) can travel. In early May 2015, deformation data, seismic data, and an abrupt drop in the level of the lava lake in Kilauea's summit crater suggested movement of magma from beneath the summit to beneath its upper Southwest Rift Zone. IfSAR data confirmed this movement when two COnstellation of small Satellites for the Mediterranean basin Observation (COSMO)–SkyMed synthetic aperture radar images taken a few weeks apart with the same imaging geometry created an interferogram pinpointing the area of uplift caused by magma intrusion. IfSAR provided a valuable regional view of deformation on a volcano to complement data from ground-based monitoring instruments and provided an opportunity to model magma volume and depth, refining our understanding of the inner workings of volcanoes.

Oso Landslide: Fluvial Geomorphology

The massive Oso landslide in western Washington State deposited material over the entire width of the North Fork Stillaguamish River valley, causing the river to pool until water overtopped the landslide deposit and began incising a new channel. The uncertain stability of this new channel posed a potential hazard to the adjacent highway, while its progressive deepening and widening represented a substantial source of sediment for the river. To monitor the evolution of the newly formed channel, USGS scientists used a photogrammetric technique known as Structure from Motion (SfM). Conceptually similar to the process of extracting elevations from photo stereo pairs, SfM takes advantage of modern

computational power and advances in computer vision to rapidly generate dense three-dimensional point clouds from photos that image a scene from multiple perspectives. Using a simple point-and-shoot camera mounted to a small plane, scientists generated 0.5-meter digital elevation models with positioning accuracies on the order of centimeters. The low cost per flight, in combination with the quick and straightforward processing pipeline, allowed scientists to acquire detailed topography every two to three weeks over the entire flood season and provide regular checks on changing channel alignments, as well as accurate estimates of erosion volumes. More information is available online at *http://wa.water.usgs.gov/projects/sr530/remotesensing.htm*.

Polarimetric Radar, Oil Spill, and Gulf Coast Marshes

Polarimetric synthetic aperture radar (PolSAR) data collected by NASA's Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) aircraft documented initial impacts and continue to monitor effects of the Deepwater Horizon (DWH) oil spill on Gulf Coast marshes (*http://dx.doi.org/10.1016/j.marpolbul.2014.10.032*). Researchers used ground, optical, and PolSAR data to map heavy shoreline oiling; however, only PolSAR mapping identified an expansive area of interior marsh that showed dramatic change from pre-spill conditions in 2009 to post-spill conditions in 2010, even though no oil intrusion into the interior marshes was detected during the event in 2010. To determine whether the PolSAR change in interior marshes might be related to the DWH oil spill, researchers collected sediment samples along shorelines and within interior marshes in 2011, one year after the DWH spill. Analytical chemists at Louisiana State University and remote sensing analysts from USGS and NASA together determined that DWH oil extended beyond shorelines, suggesting that the oil spill could have affected much more of the southeastern Louisiana marshland than originally concluded from ground and optical surveys. Although a causal relationship cannot be proven in interior marshes, results also verified a spatial association between PolSAR change and oil occurrence. The UAVSAR system, with on-demand response, high spatial resolution, high repeat targeting, and high canopy-penetration capability, demonstrated its capability as a possible prototype for an oil-mapping system.

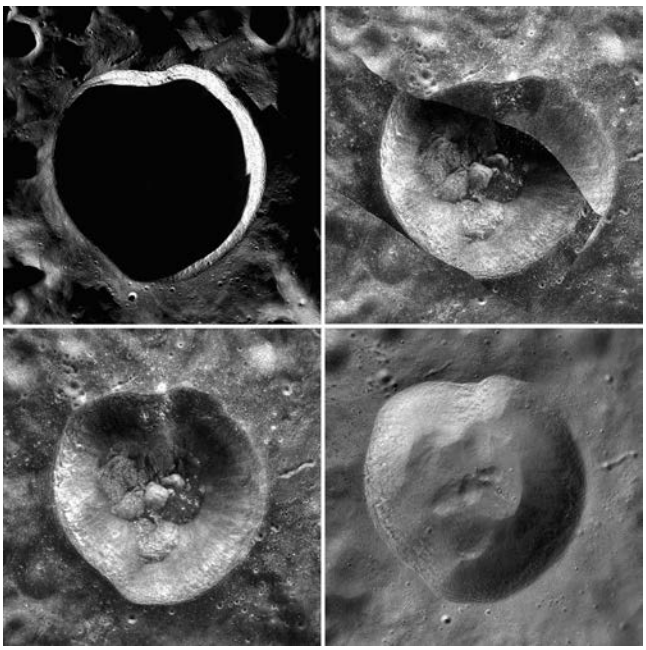
More information is available online at *http://cce.nasa.gov/cgi-bin/cce/cce_profile.pl?project_group_id=2914*.

Snow Depth Variability on Glaciers in Alaska

A quantitative understanding of snow accumulation on glaciers is essential to understanding glacier mass balance and provides insights into a wide range of scientific and resource management topics. The USGS Alaska Science Center continued using 500-megahertz ground penetrating radar (GPR) to map snow accumulation at multiple glaciers. This spatial variability allowed scientists to quantify the importance of regional controls, such as distance from moisture sources and rain-shadow effects from topographic features, as well as local controls that included terrain parameters such as elevation, aspect, slope, and shelter from prevailing winds. Multi-variable regressions with terrain parameters on a glacier-by-glacier basis indicated elevation as the dominant local control, while other terrain parameters varied in importance. Although local parameters described much of the variation in snow, the models could not explain 20–40 percent of the observed variability, suggesting additional important processes. More information is available online at *http://www.usgs.gov/climate_landuse/clu_rd/glacierstudies/default.asp*.

Unveiling the Dark Side of the Moon

Permanently shadowed craters near the poles of the Moon may contain substantial ice deposits. The USGS supported the search for this ice by producing high-precision cartographic products from data collected by the NASA Lunar Reconnaissance Orbiter (LRO). These products included high-resolution maps of the polar regions in visible wavelengths and photogrammetrically corrected radar maps. More information is available online at *http://astrogeology.usgs.gov*.



These images of the 20-kilometer impact crater Hermite A illustrate the challenges of mapping the lunar poles. At upper left is a mosaic of LRO Narrow Angle Camera images of the crater. The resolution is 0.5 meters per pixel, but the interior of the crater is permanently hidden in shadow. At the upper right is a preliminary mosaic of Mini-RF radar images. The radar "sees" into the entire crater, but errors in our knowledge of the spacecraft's position when it took the different images in the mosaic result in substantial distortions. By tying the images together and solving for more accurate spacecraft positions, USGS cartographers produced a seamless mosaic (lower left). This image clearly depicts the interior of the crater in a realistic manner and aligns precisely with other kinds of data, permitting scientists to make detailed analyses. For example, by combining the mosaic with another one containing Mini-RF images illuminated from the opposite direction, intrinsic differences in radar brightness of the surface can be canceled out, producing a detailed image of the surface topography (lower right).

U.S. Fish and Wildlife Service

The U.S. Fish and Wildlife Service (FWS), in concert with its international, Federal, tribal, state, local, and nongovernment organization partners, uses a large number of remote sensing technologies to find optimal solutions to monitor and manage fish and wildlife populations, habitats, waters, wetlands, and landscapes. The FWS utilizes acoustic GPS and radio telemetry sensors on fish and wildlife for time and location information tied to a variety of remote sensing image products, such as aerial and satellite optical imagery, as well as thermal, radar, sonar, and lidar imagery.

Floodplain Inundation Frequency in the Gulf Coastal Plains and Ozarks Region

The extent and condition of large river floodplains greatly affect the quality of fish and wildlife habitat and the supply of important ecosystem goods and services. To better understand patterns of floodplain inundation, scientists used 1,334 Landsat images over 51 Landsat scenes collected under a variety of hydrologic conditions from 1983 to 2011. Scientists classified each image into categories of wet and dry and, then, composited all images to develop a measure of relative floodplain inundation frequency for each Landsat scene (15–40 images per Landsat scene). Scientists developed an analytical methodology to link inundation frequency with gage measurement to develop measures of flood return frequency that could be tailored to the specific requirements of an individual species. Then, scientists merged the results from all 51 scenes to form a regional landscape mosaic of relative floodplain inundation frequency. These datasets have been used to determine optimal alligator gar (a giant freshwater fish) spawning locations along the lower Mississippi, Arkansas, and Trinity Rivers. This regional mosaic has also been used to inform land conservation prioritization in the Atchafalaya Basin and Mississippi Alluvial Valley, to estimate denitrification capacity within the Atchafalaya Basin, and to identify suitable environmental conditions for lidar acquisition.

Estimating Prescribed Fire Effects on Semidesert Vegetation Composition and Structure

National Wildlife Refuge System, Division of Biological Sciences

Semidesert grasslands in the arid Southwest have been substantially altered since the late 1800s by heavy livestock grazing, prolonged drought, and disrupted fire regimes. Prescribed fire plays a vital role in restoring the grassland vegetation and fuel bed conditions once maintained by frequent fire regimes. However, current fire management activities implemented at local to landscape scales must be compatible with the specific habitat requirements of threatened and endangered gallinaceous birds. Resource managers at the Buenos Aires National Wildlife Refuge (BANWR) in southern Arizona juggle these dual environmental imperatives while providing

habitat for threatened and endangered plant and animal species, with an emphasis on the critically endangered masked bobwhite quail (*Colinus virginianus ridgwayi*).

FWS Southwest Fire Management and Inventory and Monitoring (I&M) Programs have sought to map fire perimeters greater than or equal to 9.9 acres (four hectares) in size using Landsat time-series imagery and pre- and post-fire normalized burned area ratio (NBR) to enhance vegetation and habitat monitoring efforts on southwestern refuge lands. FWS scientists used BANWR fire perimeters to develop fire frequency strata for sampling vegetation in areas with a frequency of low (0–2 fires), medium (3–4 fires), and high (5 fires or more) over the last three decades. Scientists also used data layers comprising three hillslope categories and 50-meter-buffered roads to locate vegetation plots within the BANWR masked bobwhite management zone. Scientists categorized most fires within the zone as prescribed burns conducted between 1985 and 2014. Multivariate analyses indicated that semidesert vegetation composition on plots (n = 116 plots) appeared significantly different ($A = 0.04$, p-value < 0.001) among all three fire frequency strata. Areas with high fire frequency strongly correlated with high fine-fuel biomass dominated by Lehmann lovegrass (*Eragrostis lehmanniana*), an invasive perennial bunch grass introduced from South Africa in the 1930s. Areas of low to moderate fire frequency may favor a greater abundance of native plants or lack site conditions suitable for *E. lehmanniana*.

Mapping Dynamics of Wetlands in the Pacific Flyway

Intermountain West Joint Venture, Division of Migratory Birds

Researchers examined patterns of wetland availability and land-use practice within keystone migratory bird habitats in the Pacific flyway (southern Oregon and northeastern California). The results provided decision support for conservation partners to evaluate wetland and land-use benefits through an increased understanding of annual resource availability and water-use practices. Researchers modeled spatiotemporal dynamics in wetland productivity from freely available Landsat imagery to correlate satellite indices with net primary production, soil moisture, and open water extent over a 31-year span (1984–2015) to account for annual climatic variability. Images acquired from early spring through fall at

16-day intervals measured seasonal changes in wetland condition. The results of this analysis identified bottlenecks in seasonal resource availability potentially affecting life-cycle needs of migratory birds and other wetland associated species. Researchers estimated the public and private land contribution to resource availability by evaluating patterns of land tenure influenced through annual and seasonal shifts in wetland condition.

MacFarlane Reservoir Bathymetric Survey, Arapaho National Wildlife Refuge

The Water Resources Division of the Region 6 FWS generated elevation data for the creation of a storage-capacity curve for MacFarlane Reservoir, which supplies water to the Arapaho National Wildlife Refuge (ANWR), located in north-central Colorado, and provides nesting and migration habitat for several bird species. An accurate storage-capacity curve is critical for design and analysis related to future repair work on the reservoir. The project involved collecting both bathymetric data and land and spillway elevations. Researchers collected bathymetric elevations of the reservoir bottom using the SonTek HydroSurveyor system, which consists of data-processing software, Real-Time Kinematic Global Positioning System (RTK-GPS), and a five-beam depth Acoustic Doppler Profiler (ADP) mounted to a boat. They collected land elevations by walking the perimeter of the lake with a Leica GPS 1200+ Global Navigation Satellite System (GNSS) base station with 1230+ SmartRovers. Researchers post-processed and merged all location data to create a dataset containing 166,000 elevation points; created a triangulated irregular network (TIN) and surface elevation rasters using Esri ArcGIS software; and, then, wrote a Python script to calculate the volume of water stored in the reservoir at different water surface elevations, yielding the storage-capacity curve.

Bureau of Land Management

The Bureau of Land Management (BLM) requires field-based measurements to support management decisions covering vast expanses of land. The BLM is developing a core set of integrated and scalable remote sensing tools to provide an integrated, quantitative monitoring approach to efficiently and effectively document

This orthophoto mosaic was derived from UAS-collected imagery of the Henry Smith Archaeological Site. North is oriented toward the top of the image.

the impacts from authorized and unauthorized disturbance and land-treatment activities at local and regional scales.

Archaeological Site Characterization, Malta, Montana

In April 2015, the Bureau of Land Management National Operations Center (NOC) partnered with the BLM HiLine District Office in Montana to collect imagery over the Henry Smith archaeological site near the small town of Malta. The Henry Smith and Beaucoup sites are located in the Big Bend of the Milk Cultural Area of Critical Environmental Concern (ACEC), which encompasses nearly 2,000 acres (809 hectares) in north-central Montana. The project also included a first-of-its-kind prescribed burn over a known cultural site to remove vegetation so that a more thorough and accurate aerial mapping mission could be accomplished. Products derived from this project included digital surface models and orthophotography.

Buffalo Field Office Cheatgrass Orthoimagery Project

The Wyoming State BLM continues to use digital aerial imagery to identify cheatgrass (*Bromus tectorum*) in a portion of the greater sage-grouse core and connectivity areas in northeastern Wyoming. Cheatgrass degrades sage-grouse habitat

mainly by carrying fire through the landscape and incinerating nests, eggs, and young. In 2015, the Buffalo Field Office contracted with the Wyoming Department of Transportation to collect digital aerial imagery for approximately 475 square miles (125,000 hectares) to identify cheatgrass in the cure stage and plan treatments for infestations to improve sage-grouse habitat. The 2015 area of interest included sections intensively developed for coalbed natural gas from 2003 to 2011, now being reclaimed.

U.S. Bureau of Reclamation

The Bureau of Reclamation (BOR) uses Landsat data to help monitor consumptive water use, map irrigated crops for estimating water demand, and monitor interstate and inter-basin water compact compliance throughout the western United States. Lidar data, multispectral aerial imagery, and sonar data also guide activities for ecological restoration of rivers in the West.

Colorado River Delta: Water for the Environment and Environmental Benefits

In 2012, the United States and Mexico signed the historic Minute 319 Agreement to improve binational water management of the Colorado River system. The agreement allowed for a one-time "pulse flow" release of 105,392 acre-feet (130 million cubic meters) of water from the Morelos Dam on the U.S. (Arizona)-Mexico border in March 2014 to restore the dry downstream stretch of the Colorado River Delta. Bureau of Reclamation scientists continued tracking the immediate and long-term effects of the flood pulse on the delta ecosystem using pre-pulse baseline vegetation information derived from WorldView-2 satellite imagery and lidar data, and they used Landsat and Moderate Resolution Imaging Spectroradiometer (MODIS) data to analyze post-pulse biologic and hydrologic effects. More information is available online at *http://www.usbr.gov/lc/region/feature/minute319.html*.

Road Planning at a Recreation Area

DOI Dakotas Area Office Reclamation Rural Water Division, Facilities and Engineering Division, Operations and Maintenance, and Environmental Resource Division

The DOI Dakotas Area Office (DKAO) used IfSAR point cloud data to create a new 1-foot (0.3-meter) contour map to assist with a facilities engineering project to construct a recreational vehicle (RV) turnaround and cleaning station that could handle six RVs at one time, with an access road at least 150 feet (45.7 meters) from a county road corner for safety. The map also identified a section of an existing BOR gravel road that is too steep for maintenance and durability, prompting its closure and the diversion of traffic onto an alternate roadway.

Office of Surface Mining Reclamation and Enforcement

The Office of Surface Mining Reclamation and Enforcement (OSMRE) remote sensing program provides high-resolution satellite imagery, aerial photography, and lidar data to analyze terrain, vegetation, and hydrologic function on active mine sites to ensure that reclamation is consistent with the approved mining permit. These data also support inventory, monitoring, and assessment of abandoned mine land features to ensure that there is no threat to the environment or to health and human safety.

Underground Coal Fires in New Mexico

Underground coal fires can burn for years, presenting a serious health and environmental hazard. The New Mexico Abandoned Mine Land Program (NMAMLP) has contracted for several coal-fire assessments to assist with the development of mitigation/extinguishment plans for four underground coal fires in northern New Mexico: two in close proximity to Gallup, one north of Farmington, and one south of Raton. OSMRE funded the program and its reclamation projects through grants in accordance with the Surface Mining Control and Reclamation Act (SMCRA).

In 2014–15, NMAMLP contracted Koveva, Ltd., to characterize the coal fires, including identifying local sources of fuel, estimating the extent and direction of fire propagation, and providing fire mitigation options derived from decision tree analysis methods. The contractor conducted ground surveys using a Trimble handheld GPS to map surface features such as mine workings, surface fissures, subsidence, and borehole locations; a Landtec GEM 5000 gas analyzer to identify combustion gases; a Picarro H0101 to measure methane flux from the ground above the suspected combustion zones; and a Geometric G-859 magnetometer to measure changes in magnetite minerals in rocks composing the overburden above the burning coal seam to map three detection regions: burned and cooled, actively burning, and unaltered. At the Biava (Gallup) site, the surveys indicated two distinct coal fires, a north fire and a south fire. Koveva data indicated that the south fire likely started at the ash outcrop in the southwest, burned into the formation to ignite coal underground, and moved northeast.

National Park Service

The National Park Service (NPS) Inventory and Monitoring Program conducts baseline inventories for more than 270 parks across the Nation, using remote sensing data for information regarding geology, soils, vegetation, and infrastructure. Aerial photography and satellite imagery have been utilized to compile vegetation maps, a monumental task given that the agency has responsibility for over 30 million acres (over 12 million hectares) and particularly critical for the remote and vast expanses of public land in Alaska. The NPS takes advantage of the free Landsat archive to quantify decadal changes in glacier ice cover and document land-cover change in national park units. NPS has sponsored the DOI Monitoring Trends in Burn Severity project to map all large wildland and prescribed fires using the Landsat archive. GPS also supports field data collection, navigation, and search-and-rescue operations conducted by the agency.

Monitoring Coastal Change with High-Resolution Satellite Imagery in Alaska's Arctic National Parks

Arctic Inventory and Monitoring Network

The NPS continued using WorldView-2 high-resolution satellite imagery to monitor coastal change in Alaska's arctic national parks with the help of the University of Alaska Fairbanks (UAF). The well-documented decrease in arctic sea ice cover in recent decades has raised concerns that the extensive coastlines of Cape Krusenstern National Monument and Bering Land Bridge National Preserve could be experiencing accelerated erosion and other detrimental impacts. The NPS obtained high-resolution satellite imagery in 2013 and 2014 through the USGS Commercial Remote Sensing Space Policy (CRSSP) program (*http://crssp.usgs.gov/*) and used volunteers at UAF to compare shoreline positions and coastal landforms on these images with those from earlier satellite images and historical aerial photographs. Preliminary results showed interesting changes, such as the rapid erosion of ice-rich permafrost bluffs, large overwash events on low-lying barrier islands, spit formation, and lagoon breaching. More information is available online at *http://science.nature.nps.gov/im/units/arcn/vitalsign.cfm?vsid=7.*

National Hydrography Dataset Update in Glacier Bay National Park and Preserve

The Geographic Information Systems (GIS) Team conducted a comprehensive update and densification of interior National Hydrography Dataset (NHD) data features for Glacier Bay National Park and Preserve (GLBA). The GLBA NHD updates required a traditional image interpretation and manual data-editing process with key layers using Pleiades-1A, 0.5-meter resolution, color infrared (CIR) satellite imagery for visual validation of hydrography features, and IfSAR elevation data for validating water flow paths across the landscape surface. The CIR image captures reflectance data in the visible green through near-infrared (NIR) wavelengths, helping interpreters to more effectively identify locations of water features since water clearly appears as black areas in the NIR wavelengths.

Between 2003 and 2014, high waves breached the beach ridge on this barrier island in Bering Land Bridge National Preserve, Alaska, to form a new overwash feature.

Bureau of Indian Affairs

The Bureau of Indian Affairs (BIA) applies remote sensing to activities such as planning land use, responding to non-point-source pollution affecting subsistence hunting and fishing, ameliorating climate-change effects such as sea-level rise for coastal tribes, locating and identifying potential dam hazards, and generating digital terrain data for the use of open-channel hydraulics.

Classifying Forest Types Using Remotely Sensed Imagery

The Penobscot Nation in Maine, a federally recognized Indian tribe, utilized remote sensing imagery to map forest resources on their reservation. The tribe hired a contractor to capture aerial color imagery at a scale of 1:15,840. After post-collection analysis of the acquired imagery, the contractor created a forest cover map for the 14,000-acre (5,666-hectare) Lakeville parcel. The map incorporated minor and major tree species (hardwoods and softwoods), stand density, and forest floor cover. This forest map enables the Penobscot Nation Forestry Program to determine which areas require silvicultural treatments.

Improving Tribal Land Management Through Remote Sensing

In 2015, the USGS program TEchnical training in Support of Native American Relations (TESNAR) sponsored the USGS Western Geographic Science Center (WGSC) in providing training to staff of the San Carlos Apache Tribe on land-management applications of airborne laser scanning (lidar) and field-based multispectral imaging and monitoring. The 1.8-million-acre San Carlos Apache Reservation in east-central Arizona, the third largest reservation in the U.S. Southwest, encompasses diverse topography and ecology that support a broad array of vegetation types and habitats, from forest and woodland to grassland and desert. The San Carlos Apache Tribe's economy depends on sustainable forestry and ranching, making effective land management critical because of the challenges of persistent drought and climate change, along with limited personnel and financial resources.

Federal Communications Commission

FCC

The Federal Communications Commission (FCC) formulates rules to facilitate the provision of commercial satellite services in the United States. It also issues licenses for the deployment and operation of all nongovernmental U.S. satellites. Internationally, the FCC coordinates satellite radio-frequency usage with other countries. The FCC's accomplishments for FY 2015 related primarily to commercial communications and remote sensing satellites, as well as amateur and experimental satellites.

In FY 2015, the FCC authorized a number of commercial communication satellite deployments and operations. These authorizations included the following:

- January 22, 2015: To Intelsat License, LLC, to construct, deploy, and operate a C- and Ku-band satellite at the longitude 55.5° west orbit location, which will take over service from the Intelsat 805 and Galaxy 11 satellites.
- March 4, 2015: To DIRECTV Enterprises, LLC, to construct, deploy, and operate a Ku-band satellite at the longitude 45.2° west orbit location. DIRECTV plans to provide high-definition programming to Brazil.
- March 12, 2015: To DISH Operating, LLC, to construct, deploy, and operate a direct broadcast service satellite at the longitude 109.9° west orbit location, which will take over service from the EchoStar 10 satellite.
- April 2, 2015: To SES Americom, Inc., to operate a C- and Ku-band satellite at the longitude 103° west orbit location, as a replacement for the AMC-1 satellite. The portion of the satellite capable of operating in the 17/24-gigahertz band is also separately authorized by Industry Canada.

- May 11, 2015: To Skynet Satellite Corporation, to deploy and operate a Ku- and Ka-band satellite at the longitude 15° west orbit location.
- May 20, 2015: To DIRECTV Enterprises, LLC, to construct, deploy, and operate a Ka-band satellite at the longitude 102.75° west orbit location.
- May 21, 2015: To Intelsat License, LLC, to construct, deploy, and operate a C-, Ku-, and Ka-band satellite at the longitude 50° west orbit location, which will take over service from the Intelsat 1R satellite.

The FCC saw an increase in the number of applications it received for experimental operations by nongovernmental small satellites—from 44 in FY 2014 to 59 in FY 2015. These satellites operate in low-Earth orbit. Many of the experimental grants by the FCC for small-satellite operations went to universities and institutions conducting research and developing new spacecraft technologies. The satellites' missions included data transmission demonstrations, Earth and space imaging, weather monitoring, atmospheric measurements, and the testing of spacecraft hardware and software in development for future missions.

The FCC continued to authorize commercial small-satellite operations as well. During FY 2015, Planet Labs, Inc., completed deployment of all the small satellites it had requested to deploy and operate under its initial FCC commercial authorization. On October 23, 2014, the FCC granted authority to Planet Labs to expand its constellation of Earth-imaging satellites by adding up to 500 new small satellites, to be deployed from the International Space Station.

In FY 2015, the FCC also granted experimental authority to Orbital ATK for the testing of a spacecraft antenna system.

The FCC granted a number of license modifications and Special Temporary Authorizations for satellite networks. Many involved routine testing or redeployment of satellites within a multi-satellite system. Several of these actions, however, warrant particular mention:

- November 26, 2014, and April 30, 2015: The FCC granted the request of XM Radio, LLC, to drift the XM-1 satellite to the longitude 39° west orbit location before beginning the process of raising the satellite to disposal orbit.
- May 28, 2015: The FCC granted authority to SES Americom, Inc., to operate its AMC-1 satellite at the longitude 129.15° west orbit location,

in accordance with the International Telecommunication Union (ITU) filings of Gibraltar.

- July 30, 2015, and September 10, 2015: The FCC granted the requests of Satellite CD Radio, LLC, to operate its FM-1, FM-2, and FM-3 nongeostationary satellites with relaxed orbital parameters in order to conserve fuel for eventual satellite disposal maneuvers.

The FCC also added two non-U.S.-licensed space stations to its permitted list to allow these space stations to provide domestic and international satellite service to U.S. earth stations that have routine technical parameters:

- November 20, 2014: The FCC added Hispasat, S.A.'s Amazonas-1 satellite to the permitted list, operating under the authority of Spain and using the Ku-band at the longitude 55.5° west orbit location. Amazonas-1 had previously been on the permitted list at a different orbit location.
- June 11, 2015: The FCC added Satélites Mexicanos, S.A. de C.V.'s Eutelsat 115 West B satellite to the permitted list, operating under the authority of Mexico and using the C- and Ku-bands at the longitude 114.9° west orbit location. Eutelsat 115 West B was authorized to replace the service provided by Eutelsat 115 West A at the same orbit location.

In addition, the FCC took several actions on requests for non-U.S.-licensed space stations to provide service in the United States on a nonroutine basis:

- January 8, 2015: At the request of Inmarsat plc, the FCC made a modification to the "ISAT List," a list of approved satellites in the Inmarsat system for U.S. earth stations to access, by changing the listed location of the Inmarsat-4 F3 satellite to the longitude 98° west orbit location.
- March 30, 2015: The FCC granted Inmarsat Mobile Network, Inc.'s application to construct and operate an earth station facility in Minnesota to communicate with the recently deployed Inmarsat-5 F2 satellite, operating under the authority of the United Kingdom and using the Ka-band at the longitude 55° west orbit location.
- June 23, 2015: The FCC granted the request of Hughes Network Systems, LLC, to modify its grant of market access to the United States for its planned Jupiter 97W satellite, using the Ka-band at the longitude 97.1° west orbit location. Hughes had requested to change the licensing authority

for Jupiter 97W from the United Kingdom to Papua New Guinea and to access the United States market using additional Ka-band frequencies.

- August 20, 2015: The FCC granted authority to Satélites Mexicanos, S.A. de C.V., to access the United States market using its planned Satmex 9 satellite, operating under the authority of Papua New Guinea and using the L-band at the longitude 117° west orbit location. Satmex 9's operations in the L-band will provide support to the Federal Aviation Administration's Wide Area Augmentation System for air navigation.

U.S. Department of Agriculture

USDA

Farm Service Agency

Since the 1930s, the Farm Service Agency (FSA) has been tasked with administering farm commodity, credit, conservation, disaster, and loan programs as laid out by Congress through a network of Federal, state, and county offices. Because everything FSA does is tied to the land, geospatial systems and data have played a fundamental role in FSA's program delivery.

FSA's core spatial dataset, the Common Land Unit (CLU) layer, is a dynamically updated, nationally consistent digital dataset representing farm and field boundaries. Integrated with associated nonspatial farm data in a common foundational system, it allowed producers to provide core information once and, leveraging advancements in geospatial technology, helped the agency ensure accurate and consistent information. FSA used geospatial data, including the CLU, to support producer crop-reporting activities and the administration of conservation, commodity, and lending programs.

Remotely sensed data, such as Moderate Resolution Imaging Spectroradiometer (MODIS), Advanced Wide Field Sensor (AWiFS), and other high-resolution aerial and satellite imagery collected as a result of interagency coordination, are examples of imagery sources used during periods of 2015 disaster recovery to support disaster programs such as the Emergency Loan and Emergency Conservation Programs.

As the primary source of aerial imagery for the U.S. Department of Agriculture (USDA), FSA administered the National Agriculture Imagery Program (NAIP),

leveraging partnership funds from other Federal, state, and local entities to acquire imagery during the growing season over the contiguous United States. In 2015, FSA acquired nearly 1.8 million square miles of four-band (natural color and near-color infrared) imagery in 25 states. FSA also advanced the Early Access Web Services (EAWS) out of initial pilot status in 2014. EAWS provided minimally processed NAIP imagery Web services, direct from the flying contractor to the end customer, between two and seven days after acquisition. This allowed FSA and partner agencies to perform time-sensitive work with the most current imagery available months in advance of receiving production-level NAIP imagery. In addition to distributing the most up-to-date NAIP imagery, FSA also hosted a large imagery archive that was accessible to Federal agencies and the public through the USDA Geospatial Data Gateway.

Foreign Agriculture Service

The Foreign Agricultural Service's (FAS) Office of Global Analysis (FAS/OGA) served as a major source of objective and reliable global agricultural production information to the USDA's monthly World Agricultural Supply and Demand Estimates (WASDE) report, the primary source of USDA's global commodity outlook. The monthly WASDE reports provided public access to information affecting world food security and crucial to decisions affecting U.S. agriculture, trade policy, and food aid. FAS/OGA used satellite imagery at regional, national, and subnational scales to monitor and analyze the impact of weather events that affected crop production, area, and yield worldwide. FAS archived and displayed global monthly crop production, supply, and distribution (PSD) data from USDA's WASDE report on the FAS PSD Online Web site (*http://apps.fas.usda.gov/psdonline/psdhome.aspx*).

The International Production Assessment Division (IPAD) operated the remote sensing program at FAS/OGA. Landsat 7 and Landsat 8 served as the primary satellites utilized by FAS/OGA/IPAD for mapping crop area and type for numerous countries worldwide, whereas and NASA's MODIS sensor on board the Aqua and Terra satellites monitored crop conditions and relative crop yields. The USDA-NASA Global Agricultural Monitoring (GLAM) Web system displayed

and archived historical MODIS-Terra (i.e., 2000–present) and MODIS-Aqua (i.e., 2002–present) imagery, and the GLAM Web interface easily allowed public users to analyze and compare current crop conditions with past years'.

FAS/OGA also maintained several public global agricultural datasets by processing, archiving, and displaying on the Web a variety of satellite imagery products. The FAS/OGA Crop Explorer Web system monitored and displayed rainfall, temperature, soil moisture, and vegetation conditions by utilizing satellite imagery from NASA's Tropical Rainfall Measuring Mission (TRMM), NASA's Global Precipitation Measurement (GPM), and NOAA's Polar-orbiting Operational Environmental Satellites (POES). In addition, the Global Reservoir and Lake Monitor (G-REALM) monitored and displayed reservoir and lake water heights by utilizing satellite radar altimeter data from NASA's Ocean Topography Experiment (TOPEX)/Poseidon, Jason-1, and Jason-2 satellites.

FAS/OGA also managed USDA's Satellite Imagery Archive (SIA) program and displayed all moderate-resolution satellite imagery archived via SIA's Archive Explorer (AE). In 2000, the USDA's Remote Sensing Coordinating Committee (RSCC) established the SIA program, which is chaired by the USDA's Remote Sensing Advisor. During 2015, the USDA/FAS purchased satellite imagery with 22-meter spatial resolution from the Deimos-1 and UK-DMC2 satellites, then archived it via SIA's AE. FAS/OGA used the Deimos-1 and UK-DMC2 satellite imagery covering the lower 48 U.S. states to map crop type for the 2015 United States crop season and to monitor crop damage caused by natural disasters such as drought, fires, diseases, or insects.

Forest Service

As the primary forestry agency of the United States and the largest agency in the USDA, the U.S. Forest Service (USFS) continues to sustain the health, diversity, and productivity of the Nation's forests and grasslands. This work encompasses partnerships with states, tribes, and other Federal agencies to address forestry and natural resource issues; administration and management of 155 national forests and 20 national grasslands collectively known as National Forest System (NFS) lands, totaling 193 million acres; and assistance to private land owners and state, tribal,

and community forestry agencies in the stewardship of approximately 500 million acres of non-Federal forest lands.

In FY 2015, the USFS collaborated with NASA, NOAA, the USGS, and other agencies to apply operational satellite and airborne imagery and the most advanced remote sensing and geospatial technologies. Specific accomplishments included the following:

- Collected comprehensive Earth Observing System (EOS), MODIS, and Suomi National Polar-orbiting Partnership (Suomi NPP) Visible Infrared Imaging Radiometer Suite (VIIRS) direct-broadcast data and Landsat 8 Operational Land Imager (OLI) data via the USGS's Earth Resources Observation Systems (EROS) for the United States and Canada. Provided operational processing and dissemination of near-real-time fire mapping and geospatial data products to fire managers and the general public. (*http://activefiremaps.fs.fed.us*)
- Continued activities with NASA Goddard Space Flight Center's Direct Readout Laboratory under a USFS-NASA interagency agreement to test and operationally implement direct-readout technologies, including land, atmospheric, and ocean science processing algorithms for EOS and Suomi NPP sensors, to support evolving resource management and operational information needs. (*http://directreadout.fs.fed.us*)
- Continued operational processing and analysis of MODIS and Landsat imagery for systematic detection of forest damage and changing forest health conditions in our Nation's forests. (*http://foresthealth.fs.usda.gov/portal/Flex/FDM?dL=0*)
- Continued to distribute 250-meter forest attribute data surfaces derived from MODIS imagery and other geospatial predictor data using nearest neighbor imputation methods. (*http://data.fs.usda.gov/geodata/rastergateway/forest_type/index.php*)
- Continued to distribute 250-meter forest carbon estimates derived from MODIS imagery and other geospatial predictor data using nearest neighbor imputation methods. (*http://data.fs.usda.gov/geodata/rastergateway/biomass/index.php*)

- Continued conducting limited operational wildfire mapping missions using the Autonomous Modular Sensor (AMS) via coordination between the USFS and NASA Ames Research Center's Airborne Science Program.
- Coordinated with Ames Research Center to further develop the AMS onboard processing system capabilities and user interface to support additional testing and integration flights on USFS aircraft.
- Continued coordination with Goddard Space Flight Center on testing and evaluation of the Multi-Angle Implementation of Atmospheric Correction (MAIAC) for MODIS, along with its potential use for land and atmospheric remote sensing applications.
- Operationally applied Earth Observing 1 Advanced Land Imager Landsat 7 Enhanced Thematic Mapper (ETM) and Landsat 8 OLI imagery to respond to approximately 188 requests to map the location, extent, and severity of large wildfires in 2014 and 2015 to support post-fire emergency stabilization/hazard mitigation activities and forest restoration planning/management activities. (*http://www.fs.fed.us/eng/rsac/baer* and *http://www.fs.fed.us/postfirevegcondition*)
- Continued to operationally apply Landsat 4/5 Thematic Mapper (TM) and Landsat 7 ETM imagery to inventory, map, and characterize historical large fires to assess the effectiveness of national fire management policies as part of the Monitoring Trends in Burn Severity (MTBS) project. MTBS mapping activities through FY 2015 include the completion of 19,200 historical fires (~142 million burned acres) spanning from 1984 to 2014. (*http://www.mtbs.gov*)
- Coordinated with the University of Maryland and NASA under the auspices of a NASA Research Opportunities in Space and Earth Sciences (ROSES) A35 Wildfires Project to implement the 375-meter VIIRS I-band active fire detection product as part of operational USFS strategic fire detection and monitoring program activities. (*http://activefiremaps.fs.fed.us*)
- Coordinated with the University of Maryland, NASA, and the USGS under the auspices of a NASA ROSES A35 Wildfires Project to execute and test Landsat 8 prototype active fire detection algorithms and evaluate derived output products to support USFS operational fire support activities.

- Continued technology transfer activities between the USFS and Ames Research Center regarding Unmanned Aircraft Systems (UAS) and related technologies under the auspices of the NASA-USFS Wildfire Research Applications Partnership and a USFS-NASA interagency agreement. (*http://geo.arc.nasa.gov/sge/WRAP/index.html*)
- Coordinated with Ames Research Center on advancing the Thermal Mapping Airborne Simulator (TMAS) (developed under the NASA Small Business Innovation Research [SBIR] program) and the Staring Wide Area Imager (StareWAI) to higher Technology Readiness Levels (TRLs), as well as phasing into USFS tactical fire-mapping operations in the future.
- Used imagery from Landsat 5 TM and from Landsat 8 OLI and NAIP to initiate, complete, and update mid-level vegetation-mapping products for national forest lands and adjacent land areas throughout the country.
- Completed Tree Canopy Cover (TCC) data for the continental United States, Alaska, Hawaii, Puerto Rico, and the U.S. Virgin Islands using imagery from Landsat 5 and Landsat 8 OLI and NAIP as part of the Multi-Resolution Land Characteristics Consortium (MRLC) National Land Cover Database (NLCD) 2011 update and also initiated production on NLCD TCC 2016.
- Expanded the use of Landsat TM/ETM/OLI time-series stacks to detect and monitor forest land-cover change from the mid-1980s to the present in the watersheds of the Great Lakes and all national forests in the Pacific Northwest. This activity is now being conducted using automated change-detection capabilities in the Google Earth Engine.
- Used Landsat TM/ETM/OLI and NAIP imagery in conjunction with other core geospatial datasets to conduct ecological and soil-type mapping on NFS lands in the northeast and western United States, which the USFS, Natural Resources Conservation Service (NRCS), and other agencies apply to resource management, planning, and decision making. (*http://www.fs.fed.us/eng/rsac/programs/teui/about.html*)
- Progressed toward a comprehensive and consistent land-cover/land-use monitoring system, the Landscape Change Monitoring System (LCMS),

for the continental United States. LCMS utilizes Landsat TM/ETM/OLI time-series stacks to detect and monitor land-cover/land-use change from the mid-1980s to the present across all administrative ownerships. This effort is being conducted in collaboration with several Federal and academic partners. (*http://larse.forestry.oregonstate.edu/lcms-landscape-change-monitoring-system* and *http://landsat.gsfc.nasa.gov/?p=10868*)

- Continued to develop standards and practices for integrating light detection and ranging (lidar) into forest and resource management (i.e., defining acquisition specifications, data-quality assessment, analysis/modeling procedures for forest parameters, etc.). Continued to expand USFS involvement in the USGS 3D Elevation Program to ensure consistent acquisition specifications and to minimize redundant collections by partnering with other state and Federal entities on data acquisitions.
- Continued working with the NASA Applied Remote Sensing Training (ARSET) program to enhance NASA and Forest Service remote sensing training programs and leverage existing Forest Service training investments to increase awareness about emerging technologies and practical resource applications.

National Agricultural Statistics Service

The National Agricultural Statistics Service (NASS) used remote sensing data to construct and sample area frames for agricultural statistical surveys, to estimate crop area and yield, and to continue contributing to a NASA science grant on fallowed California agricultural land. Additionally, NASS published papers describing a new area frame stratification method based on geospatial crop-planting frequency data layers and an interdisciplinary methods paper on crop yield.

NASS used Landsat imagery, digital NAIP orthophoto quadrangles, and other remotely sensed inputs for the contiguous United States and Puerto Rico to select the yearly area-based samples for the June Agricultural Survey. In addition, NASS updated new area-based sampling frames for Nebraska and Wisconsin.

NASS fully implemented the geospatial Cropland Data Layer (CDL)–based automated stratification method into area frame operations, resulting in new state

area frames being built at reduced cost with improved objectivity, efficiency, and accuracy. The CDL data are used as the basis for the objective stratification of NASS area frame primary sampling units rather than visual interpretation of aerial photography or satellite data.

The remote sensing acreage estimation program used Disaster Monitoring Constellation (DMC) and Landsat data to produce crop acreage estimates for crops at the state and county levels during the 2015 crop year. Acreage estimates were created for all market-sensitive crops and states. NASS's Agricultural Statistics Board (ASB) was able to utilize the remote sensing acreage indications as independent input for setting the official estimates for its monthly Crop Production Reports. Analysts derived remote sensing–based acreage indications from the CDL. The primary satellite imagery inputs were from the Foreign Agricultural Service's Satellite Imagery Archive, which provided growing-season coverage with DMC imagery through a cooperative partnership while utilizing growing-season Landsat 8 imagery. In addition, NASS distributed the CDL for 48 states to stakeholders for the previous 2014 crop season via the USDA Geospatial Data Gateway and the CropScape data visualization portal at *http://nassgeodata.gmu.edu/CropScape*.

NASS utilized NASA MODIS Normalized Difference Vegetation Index (NDVI) products for modeling corn and soybean yield indications over the 12 largest production states. Updated yield estimates were delivered operationally to the ASB as an independent indication for setting official August, September, and October yield estimates by state, district, and county. MODIS Land Surface Temperature (LST) products served as an independent variable for yield estimation.

NASS is developing a Decision Support System, in collaboration with researchers from the University of Florida and the University of Nebraska, to improve yield forecasts using crop indicators obtained during critical stages of the crop's growing season. A study is being conducted that focuses on the evaluation of the potential use of satellite data, crop simulation models, and/or mathematical models to develop critical crop indicators. Research objectives include 1) the determination of corn and soybean phenological critical stages; 2) how critical stages can be predicted or identified using remote sensing, mathematical models (i.e., crop simulation models), and/or a combination of these techniques; 3) how to retrieve

and relate information about soil moisture, spectral reflectance, and other available products during critical stages; and 4) how to develop metrics at critical stages or critical crop indicators to improve corn and soybean yield forecasts.

The Web-based national vegetation condition geospatial portal VegScape (*http://nassgeodata.gmu.edu/VegScape*) continued to deliver timely crop condition vegetation indices based on MODIS daily, weekly, and biweekly products throughout the growing season. VegScape showed crop condition/vegetation greenness and drought anomaly assessments. NASS continued work on a NASA science grant titled "Fallowed Area Mapping for Drought Impact Reporting and Decision Making," to which NASS contributed monthly growing-season CDL-based fallowed land estimates for California water resource stakeholders.

This page is intentionally left blank.

National Science Foundation

NSF

The National Science Foundation (NSF) continued to serve as the lead Federal agency for the support of ground-based astronomy and space science. Through the divisions of Astronomical Sciences, Atmospheric and Geospace Sciences, Polar Programs, and Physics, the NSF sponsored a broad base of observational, theoretical, and laboratory research aimed at understanding the states of matter and physical processes in the universe. Areas of research ranged from the most distant reaches of the universe and the earliest moments of its existence to nearby stars and planets—including our own sun and planetary system—and Earth's atmosphere and space environment.

Division of Astronomical Sciences

The Division of Astronomical Sciences (AST) within the Mathematics and Physical Sciences (MPS) Directorate supported the development of advanced technologies and instrumentation for astronomical sciences, in addition to providing core support for the optical and radio observatories with state-of-the-art instrumentation and observing capabilities accessible to the community on the basis of scientific merit. The NSF's national astronomical facilities included the National Radio Astronomy Observatory (NRAO), the Arecibo Observatory (AO), the National Optical Astronomy Observatory (NOAO), and the National Solar Observatory (NSO). The NSF also served as the executive agency for the Gemini Observatory—an international partnership operating optical/infrared telescopes

in both the Northern and Southern Hemispheres—providing the United States' share of support for the program.

During FY 2015, AST, in partnership with Europe, Canada, Japan, Republic of Korea, and Taiwan, completed construction of the Atacama Large Millimeter/submillimeter Array (ALMA), an interferometer located near San Pedro de Atacama, Chile. Science operations continued with a steadily increasing set of capabilities, and researchers obtained spectacular images of planetary systems in the process of formation.

AST continued its oversight of the Daniel K. Inouye Solar Telescope (DKIST—previously referred to as the Advanced Technology Solar Telescope, or ATST), the next-generation U.S. ground-based solar telescope. DKIST is the result of a collaboration of scientists from more than 20 institutions representing a broad segment of the U.S. solar physics community, and it had previously earned the strong recommendation of the National Research Council of the National Academy of Sciences. When completed in 2019, DKIST will be the world's flagship ground-based telescope designed specifically for the study of solar magnetic fields on scales as small as 30 kilometers. In August of 2013, the National Science Board approved a new baseline cost for the DKIST project of $344.13 million. The fabrication of the major telescope subsystems and instruments is ongoing, as is the construction of the facility on the Haleakala, Hawaii, site. As of the end of FY 2015, the project is currently on budget and scheduled to begin operations in late 2019. Construction of the DKIST facility is led by the National Solar Observatory (NSO). In August of 2014, the National Science Board approved the renewal of the cooperative agreement (CA) for the operations and management of the NSO for a period of ten years. The renewed CA and a new cooperative support agreement (CSA) passed in June of 2015, with the approved budget including a funding ramp for the DKIST operations beginning in FY 2015 and increasing to a steady-state cost of approximately $17 million in FY 2019, with costs beyond 2019 adjusted for inflation.

The importance of the potential impacts of space weather on the Nation's critical infrastructure has raised the level of awareness of space weather within the Federal Government. Personnel from MPS/AST, along with colleagues from the Directorate for Geosciences (GEO)/Atmospheric and Geospace Sciences (AGS), participated in the National Science and Technology Council's (NSTC) Space

Weather Operations, Research, and Mitigation (SWORM) multi-agency task force. The NSTC tasked SWORM with developing a National Space Weather Strategy (NSWS) and an associated National Space Weather Action Plan. The White House Office of Science and Technology Policy (OSTP) hosted an event rolling out the NSWS entitled "Enhancing National Preparedness for Space-Weather Events." This increased level of awareness of space weather has resulted in renewed interest in the data products provided by NSO's Global Oscillations Network Group (GONG) facility, which provides detailed synoptic solar data crucial to operational space weather forecasting. This interest led to the development of a draft Memorandum of Understanding (MOU) between the NSF and the National Oceanic and Atmospheric Administration (NOAA) for joint funding in support of GONG operations and the continued production of GONG operational data products.

In FY 2015, technicians began the construction of the Large Synoptic Survey Telescope (LSST) project. NSF project managers negotiated and issued major contracts for the site and building in Chile, the telescope mount assembly (the major moving pieces), the dome, the mirror support systems, and many other parts. The innovative M1M3 (primary/tertiary mirror) mirror complex passed its acceptance tests and went into storage. Meanwhile, the NSF's Federal partner, the Department of Energy (DOE) Office of High Energy Physics (HEP), received Critical Decision–3 (CD-3) approval to spend equipment funds on major items. LSST met their last Critical Decision milestone, which gained them full project support from the NSF. In its ten-year prime mission, imaging the entire accessible sky many hundreds of times, the survey will populate a science-ready database of unprecedented size, enabling breakthrough research in dark energy and dark matter, in galactic structure, and in solar system astronomy. Its relentless repeated observations will also open up the time domain and will revolutionize the study of transient events. At the end FY 2015, construction remained on schedule for "first light" in 2020, followed by two years of commissioning to shake down and tune all the complex interrelated operating systems. The NSF expects full science observing to start in 2022 and to generate 30–40 terabytes every night, night after night, for at least ten years. DOE is funding the camera in a project led by the Stanford Linear Accelerator Center (SLAC) National Accelerator Laboratory. The NSF funded the telescope, building, site, network and software pipelining, and

data management systems that allow specialized access separately for research and for education and public outreach. Long-lead-time items and technology development essential for mitigating risks identified early in the project came from private funding. The NSF and DOE planned to support installation and commissioning together and to augment their operations funding by negotiating contributions from international partners.

The Atacama Cosmology Telescope (ACT) is a six-meter-diameter millimeter-wave telescope located at 5,200 meters (17,000 feet) on Cerro Toco in the Atacama Desert of northern Chile, near the ALMA site. It is designed to measure minute variations in the intensity of the cosmic microwave background (CMB)—the radiation at microwave wavelengths that is a remnant of the Big Bang—to study how the universe began, what it is made of, and how it evolved to its current state. In FY 2015, project personnel observed with and analyzed data from a new camera called ACT Polarimeter (ACTPol), which studies the polarization properties of the CMB. AST's Mid-Scale Innovations Program (MSIP) granted a new five-year award to undertake development of an upgrade to the ACTPol receiver designed to operate at four frequencies, based upon new multi-chroic detectors (allowing increased sensitivity and spectral resolution) developed by the ACT team with NASA support.

The Polarization of Background Radiation (POLARBEAR) telescope is a three-meter-diameter off-axis millimeter-wave antenna designed to measure, like ACTPol, the polarization of CMB radiation to search for "B-modes" with a very large field of view. The observatory is located near the ACT and ALMA facilities on the Chilean Atacama plateau. In FY 2015, construction began on two additional telescopes under private funding from the Simons Foundation, including the pouring of concrete pads and other infrastructure developments. Also in FY 2015, MSIP granted a new award to support observations and data analysis with the new three-telescope POLARBEAR configuration.

Division of Atmospheric and Geospace Sciences

The Geospace Section (GS) within the Division of Atmospheric and Geospace Sciences (AGS) supported a wide variety of research programs in space science in

FY 2015. These included the funding of advanced radar systems to study the ionosphere and magnetosphere, ground-based optical equipment to study the aurora and airglow, partial support to ground-based solar telescopes and instruments, and a wide-ranging portfolio of basic research in space physics. Major GS-funded activities in FY 2015 included the Geospace Facilities (GF) program; the Space Weather Research (SWR) program; the Coupling, Energetics, and Dynamics of Atmospheric Regions (CEDAR) program; the Geospace Environment Modeling (GEM) program; and the Solar, Heliosphere, and INterplanetary Environment (SHINE) program.

The NSF implemented the GS's Faculty Development in Space Sciences (FDSS) Program in FY 2004 to ensure the health and vitality of solar and space sciences within university teaching faculties; it offers five-year awards for the creation of new tenure-track faculty positions within the intellectual disciplines that compose the space sciences. FDSS made two new awards in FY 2015 under this program, resulting in one new space physicist hired as tenure-track faculty at the University of Minnesota and a search process launched for another hire at the University of Illinois at Urbana-Champaign.

In FY 2015, the AGS approved the development of an airborne infrared spectrometer (AIR-Spec) for coronal emission line observations. AGS planned the instrument for making measurements of the solar corona in the infrared spectrum during total solar eclipses, such as the upcoming North American event on August 21, 2017. AGS designed AIR-Spec to fly on the NSF/National Center for Atmospheric Research (NCAR) Gulfstream V research aircraft, making it possible to avoid subpar weather conditions and water vapor absorption.

Throughout FY 2015, the Community Coordinated Modeling Center (CCMC) for space weather research, cosponsored by the NSF (GS of AGS) and NASA and located at NASA's Goddard Space Flight Center, continued to provide the research community with access to state-of-the-art space weather models and conducted important model-validation activities necessary for transitioning research models into operational use.

Research facilities remained as the key component of GS efforts. The Geospace Facilities program in FY 2015 continued to enable basic research on the structure and dynamics of Earth's upper atmosphere. In particular, the CEDAR and GEM

programs conducted research efforts utilizing these facilities. Throughout FY 2015, observations made by the Advanced Modular Incoherent-Scatter Radar (AMISR) at Poker Flat, Alaska, demonstrated the unique capabilities of this new instrument, including its ability to image the ionospheric effects of auroral particle precipitation in three dimensions. These observations provided a wealth of data particularly useful to modelers interested in validating space weather models. A second AMISR system has been operating at Resolute Bay in Arctic Canada since 2009. This radar is ideally situated to observe the properties of the ionosphere in the polar cap, a region that is characterized by high ionospheric variability that often causes disruption of important navigation and communication systems.

In FY 2015, the GS continued to support its program for CubeSat-based small-satellite science missions for geospace and atmospheric research and education. During FY 2015, two projects continued to operate successfully in space and two new missions launched. All provided high-quality observations and scientific findings. Another three exciting CubeSat science projects began in FY 2015, adding new capabilities and breadth to the overall CubeSat program that, with this addition, has grown the total number of past and current CubeSat projects to 15.

In FY 2015, the GS continued to support the satellite-based Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE), which is now in its second implementation phase, AMPERE-II. AMPERE utilized the 66 networked satellites of the existing Iridium constellation to create a new facility for collecting geomagnetic field data. The AMPERE facility has been providing the first-ever global observations of the electric currents that link Earth's magnetosphere and ionosphere and the first-ever continuous global observations for tracking geomagnetic storm-time dynamics. Geomagnetic storms occur when charged particles emitted by solar flares interact with Earth's magnetosphere. Such storms can cause major disruptions of power and communications systems on the ground. During FY 2015, the data collection for AMPERE continued, and the addition of new data and software updates to the AMPERE data server facility made the data freely available to researchers.

The GS solar physics community also continued to benefit from the AST's ongoing efforts to develop and manage the DKIST being constructed in Hawaii.

Also in FY 2015, the GS continued to provide oversight for much-needed upgrades at the Owens Valley Solar Array in California.

In FY 2015, the AGS' Atmosphere Section (AS) continued to support the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC). The University Corporation for Atmospheric Research (UCAR) and its collaborator, Taiwan's National Space Organization (NSPO), designed and built the COSMIC six-satellite constellation, which launched on April 14, 2006, with the support and assistance of the U.S. Air Force's Space Test Program (STP). Shortly thereafter, data became available from the three payloads: the special space-based GPS radio occultation (RO) receivers, the so-called Tiny Ionosphere Photometers, and the Tri-Band Beacons. These data have been provided freely to the world scientific community.

COSMIC radio occultation data have been assimilated at many operational weather prediction centers, including the U.S. National Centers for Environmental Prediction (NCEP), the European Centre for Medium-Range Weather Forecasts (ECMWF), Météo France, the United Kingdom's Met Office, the Meteorological Service of Canada, Taiwan's Central Weather Bureau, and others. All of these centers have reported that RO data had a significant positive impact on numerical weather forecasts. In ionospheric studies, COSMIC RO data accelerated the development of physical models for space weather prediction by providing dense, accurate, and global electron density measurements used for model testing and initialization, including the response of the global ionosphere to the impact of solar storms.

During FY 2015, four of the six COSMIC satellites remained operational (well beyond their expected life cycle), providing 1,000 to 1,500 radio occultation profiles per day. Approximately 90 percent of real-time processed COSMIC data are available for the users and operational weather forecasting centers within three hours. COSMIC supported more than 1,100 registered users from 52 countries. In collaboration with UCAR's Unidata, COSMIC soundings have been provided in real time to support the university community. UCAR also reprocessed data to provide consistent records for the duration of the mission and produced post-processed and reprocessed data from several GPS radio occultation (GPSRO) missions of opportunity, including GPS/Meteorology (GPS/MET), CHAllenging Mini-satellite

Payload (CHAMP), Satélite de Aplicaciones Científic (SAC-C), Meteorological Operational satellite programme–A/Global navigation satellite system Receiver for Atmospheric Sounding (METOP-A/GRAS), METOP-B/GRAS, TerraSAR-X, Gravity Recovery and Climate Experiment (GRACE), and Communications/Navigation Outage Forecasting System (C/NOFS). NSF and NASA officials completed a new cooperative agreement in FY 2015, through which the two agencies will jointly fund the COSMIC mission for the duration of its expected life cycle.

Division of Polar Programs

For FY 2015, the primary activities of the Division of Polar Programs (PLR) in ground-based space science and astronomy included continued full-scale observations at the U.S. Amundsen-Scott South Pole Station with the ten-meter off-axis radio telescope (South Pole Telescope, or SPT), the battery of five small-aperture (25-centimeter) telescopes called the Small Polarimeter Upgrade for DASI (Degree Angular Scale Interferometer) (SPUD)/Keck Array, and another small-aperture Background Imaging of Cosmic Extragalactic Polarization 3 (BICEP3) telescope that observed in concert with the SPUD array. The SPT, with the SPTpol (polarization-sensitive) receiver, and the SPUD/BICEP3 array focused on cosmic microwave background B-mode polarization measurements, plus polarization caused by gravitational lensing of light coming from very far galaxy clusters.

The High Elevation Antarctic Terahertz (HEAT) robotic telescope, deployed at Ridge A at the highest point of the Eastern Antarctic Plateau, continued its successful data collection through FY 2015. The IceCube Neutrino Observatory (ICNO) also continued data collection of high-energy neutrino events through FY 2015.

Recent scientific results from SPT included publications on the detection of gravitational lensing of the CMB by galaxy clusters and respective mass maps of the universe from using all temperature and polarization information, the best constraints on the B-mode and E-mode power spectra at sub-degree scales, and the final Sunyaev-Zel'dovich (SZ) selected galaxy cluster catalog from the 2,500-square-degree SPT survey.

The updated results analyzing the B-mode polarizations signal from the BICEP2 and Keck Array ground telescopes and Planck satellite data showed that interstellar dust caused the announced B-mode signal excess.

At the end of FY 2015, the IceCube Neutrino Observatory (jointly operated at the South Pole by PLR and the NSF's Division of Physics) had collected data for almost five years from a completed array of 86 strings of optical photodetectors deployed in the ice under the South Pole Station in Antarctica at depths between 1.4 and 2.4 kilometers. The ICNO Collaboration reported in FY 2015 a total of 54 high-energy neutrino events detected that exceeded 50 teraelectronvolts (TeV) and came from anywhere in the sky. (One electronvolt [eV] is the energy an electron or proton gains when it is accelerated by a voltage of one volt; one TeV is a trillion eV; two eV is about the energy of a photon in the visible orange light band.) These events revealed the first pixels of the first pictures of the distant neutrino universe—an excellent confirmation that IceCube is opening doors to a new era in particle astrophysics.

This page is intentionally left blank.

Department of State

DOS

The Department of State (DOS) carries out diplomatic efforts to support U.S. space policies and programs internationally. DOS supports U.S. civil space activities through the negotiation of bilateral and multilateral agreements with partner countries and leads U.S. participation in numerous international space and technological activities and international organizations. DOS also maintains outreach programs to advance U.S. space and foreign policy objectives.

During FY 2015, DOS continued to lead the U.S. delegation to the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) plenary and its two subcommittees—Legal (LSC) and Scientific and Technical (STSC). State continued with U.S. participation in the Working Group on Long-Term Sustainability of Outer Space Activities (LTS). STSC tasked this Working Group with examining and proposing voluntary best-practices guidelines to ensure the safe and sustainable use of outer space for peaceful purposes and the benefit of all countries. The LTS Terms of Reference were finalized in 2011. The Working Group continued to make measured progress in FY 2015's STSC and UNCOPUOS sessions. Most notably, the Working Group's four expert groups completed their work on consensus reports containing recommendations for long-term sustainability guidelines. The work of the expert groups formed the basis for an extended set of informal and formal sessions of the full LTS Working Group during FY 2015's UNCOPUOS STSC and plenary sessions. These sessions continued with the chair's proposed consolidation of almost 30 guidelines submitted by various member countries. DOS plans to continue with its participation in the Working Group and informal meetings to seek consensus on the guidelines in FY 2016.

DOS continued to promote space weather as an important foreign-policy topic worldwide and during UNCOPUOS. The United States held a special one-day workshop titled "Space Weather Services to Build Global Resilience" on the margins of the 52nd session of the STSC in FY 2015, as part of the Space Weather agenda item. The workshop aimed to increase the participation of UNCOPUOS member states in space weather service activities, consistent with the LTS proposed draft guidelines. The workshop also informed discussions at the first meeting of the STSC's Space Weather Expert Group. The United States proposed another workshop on the margins of the 53rd session of the STSC in 2016.

DOS also participated in the interagency Space Weather Operations, Research, and Mitigation (SWORM) Task Force, which drafted the 2015 National Space Weather Strategy and the National Space Weather Action Plan between November 2014 and September 2015. DOS organized and led the development of Goal 6—Increase International Cooperation, and State will contribute to its implementation by, for example, hosting a series of international workshops and meetings, coordinating sustained U.S. participation in relevant United Nations activities, and raising awareness for space weather as a global challenge.

The United States and Vietnam held the first bilateral civil space talks on December 18, 2014, in Washington, DC. Vietnam has become increasingly active in regional and global space activities. NASA, NOAA, and the USGS and their Vietnamese counterparts agreed on new projects covering space weather, space geodesy, the use of space technologies to manage the Mekong Delta, and the exchange of Earth observation data. Discussions also covered the use of global navigation satellite systems, orbital debris mitigation, and maritime domain awareness. The United States encouraged Vietnam to accede to the UN outer space treaties and develop national space legislation. The United States and Vietnam agreed to pursue a framework civil space agreement in the next few years. The two countries scheduled the second Civil Space bilateral meeting for FY 2016.

The Republic of Korea continued its discussions with the United States on establishing a Civil Space Framework Agreement during 2015, a potential first for an Asia-Pacific nation.

The United States and the European Union continued fruitful Global Navigation Satellite System (GNSS) Working Group talks during FY 2015. Working Group C,

focusing on next-generation GNSS applications, including aviation applications, met in December 2014. The Working Group finalized its Milestone II report on Advanced Receiver Autonomous Integrity Monitoring (ARAIM) for formal release by the U.S.-EU GPS-Galileo Plenary cochairs in March 2015. Working Group B, focusing on trade and civil applications, met in June 2015 to discuss the pending EU application for a waiver of U.S. Federal Communications Commission rules requiring licensing of all receive-only earth stations operating in the United States with a non-U.S.-licensed space station (Galileo satellites in this case). Continued discussions on the planned Galileo commercial service and market access issues filled out the agenda.

The United States met with high-ranking EU officials in February, April, and August 2015 to reiterate U.S. interest in negotiating possible access to the EU Public Regulated Service signal (PRS). The EU continued work on gaining approval for its security-related Common Minimum Standards, which is necessary before the EU can receive a negotiating mandate on the PRS issue.

The U.S.-Japan bilateral Technical Working Group (TWG) met in conjunction with the Institute of Navigation (ION) Pacific Position Navigation and Timing Meeting in Honolulu, Hawaii, on April 20, 2015. At this meeting, the United States and Japan completed compatibility coordination between GPS and the Japanese Quasi-Zenith Satellite System (QZSS) four-satellite configuration. This coordination, held under the auspices of the International Telecommunication Union, ensures that the two systems will not interfere with each other.

During September 2015, the United States met with Japan in Tokyo for the sixth Civil Space Dialogue. The meeting saw productive discussions on cooperative efforts in space exploration, Earth observation, space weather, and global navigation satellite systems. Japan reported on progress in preparing for the next International Space Exploration Forum (ISEF2). Japan also discussed joining the United States in extending International Space Station operations to 2024.

The United States and Canada held bilateral GNSS talks on May 6, 2015, in Ottawa. The agenda covered Positioning, Navigation, and Timing (PNT) signal interference detection and mitigation issues, protection of critical infrastructure from GPS outages, complementary PNT systems, expansion of the space geodetic

network in Canada, space weather, and coordination on international GNSS-related issues.

On June 4–5, 2015, the second U.S.-China Civil GNSS Cooperation Dialogue occurred in Washington, DC. On June 4, participants attended technical sessions on civil GNSS service performance, aviation augmentations and applications, and GNSS compatibility and interoperability. The Plenary, on June 5, saw agreement to establish three subgroups focused on the subjects addressed during the technical working session. During the Plenary, the countries also discussed broader policy, program, and international cooperation issues, including ongoing activities of the International Committee on GNSS (ICG).

At the inaugural U.S.-China Civil Space Dialogue on September 28, 2015, in Beijing, U.S. and Chinese officials exchanged information on their respective space policies. The countries discussed further collaboration related to space debris and the long-term sustainability of outer space activities. Both sides also exchanged views on issues related to satellite collision avoidance. The two sides summarized information on national plans related to space exploration and discussed the next multilateral meeting of the International Space Exploration Forum. The two sides talked about ways to cooperate further on civil Earth observation activities, space sciences, space weather, and civil GNSS.

The fifth U.S.-India Civil Space Joint Working Group met September 23–24, 2015, at the Indian Space Research Organization (ISRO) headquarters in Bangalore. The two sides identified new potential activities to enhance a growing space relationship. The discussions had a very positive tone, with clear recognition of the expanding scope and pace of cooperation. On Earth observation, the two sides focused on improving data exchanges, conducting joint missions, collaborating on data management processes, and improving modeling and forecasting capabilities. The two sides planned to expand personnel exchanges for research activities on heliography, planetary science, and possibly other areas. On GNSS, the two sides agreed to consider increased cooperation on both technical and policy issues, including engaging private-sector actors. NASA and ISRO signed two International Agreements that relate to collaboration on the ISRO Mars Observer Mission and aircraft-based remote sensing instruments for natural resource management.

DOS continued to promote the use of GPS in Africa, working through the AfricaArray consortium and the United Nations Office of Outer Space Affairs. AfricaArray is a public-private partnership led by academic researchers at the University of the Witwatersrand in South Africa and Pennsylvania State University in the United States; it is focused on supporting training and research in Earth, atmospheric, and space sciences in Africa. At the tenth AfricaArray annual meeting, held in January 2015 in Johannesburg, DOS facilitated the travel of scientists from over 12 Sub-Saharan African countries to participate in workshops and training sessions on GPS applications on a broad spectrum of Earth and space sciences.

This page is intentionally left blank.

Department of Energy

DOE

The Department of Energy (DOE) participates in the national effort to further U.S. interests in space. Three organizations within DOE provide this capability: the National Nuclear Security Administration's (NNSA) Office of Defense Nuclear Nonproliferation Research and Development (DNN R&D), the Office of Science (SC), and the Office of Nuclear Energy (NE).

Office of Defense Nuclear Nonproliferation Research and Development

The Nuclear Detonation Detection program builds the Nation's operational sensors to monitor the entire planet from space in order to detect and report surface, atmospheric, or space nuclear detonations (NuDets). The Space-Based Nuclear Detonation Detection subprogram provides much of the Nation's capability to detect, report, locate, and identify nuclear explosions using orbiting satellites. DNN R&D develops, builds, and delivers these satellite payloads to meet interagency performance and schedule commitments and provides launch and on-orbit operational support for the current generation of the U.S. NuDet Detection System (USNDS).

Since the 1960 Vela satellite program, NNSA and its predecessors have provided the underlying science and technology capability for space-based detection of foreign nuclear weapon detonations to meet test-ban-treaty monitoring needs. This fiscal year, NNSA continued full-scale production and delivery of sensor packages to ensure that payloads are ready, as needed, to meet national security requirements. To ensure that the technologies and capabilities developed for the program support stakeholder needs, DNN R&D actively engaged in intergovernmental

working groups that reduce duplication among agencies, generate new user requirements, and improve the quality of relevant technology across the funding agencies.

The NNSA weapons laboratories—specifically Los Alamos National Laboratory (LANL) and Sandia National Laboratories (SNL)—supply the science, technology, and engineering required for USNDS, and Lawrence Livermore National Laboratory (LLNL) contributes to the end-to-end testing of USNDS. These laboratories have a unique and comprehensive understanding of nuclear weapons, as well as the signatures and observables associated with a nuclear detonation and the propagation of signals from the weapon to the sensor. Moreover, these laboratories have provided capabilities in the design, construction, calibration, deployment, and operation of satellite-based detection instruments, along with detailed modeling and analysis. As the basis for 24/7/365 global monitoring, the user/operations communities routinely have received analysis, insights, and computer codes based on this research.

Two payloads built at the NNSA laboratories accomplish the NuDets reporting mission—the Global Burst Detector (GBD) and the Space and Atmospheric Burst Reporting System (SABRS). The GBD payload is hosted on all GPS satellites, and the SABRS payload is carried on satellite hosts in geosynchronous orbit. In order to maintain a vital capability to design and implement these systems, DNN R&D supported demonstration-validation payloads to explore new technologies and new sensing modalities and to increase the Technology Readiness Level (TRL) for parts that might be used in future payload designs.

Office of Science

In FY 2015, the DOE Office of Science supported several activities that contribute to a broad range of space interests. These activities included SC fundamental research that is of mutual interest to the NASA mission and NASA researchers as well as to SC staff, collaborative research efforts with NASA, and the operation of SC scientific facilities that are available to NASA and the broader scientific community for space-related research.

SC supports fundamental research in plasma science that contributes to SC-NASA mutual interests in knowledge of heliospheric and astrophysical systems.

Some of the research supported by SC's Office of Fusion Energy Sciences (FES) advances the development of a comprehensive understanding of heliospheric and astrophysical magnetized-plasma processes, including Alfvén wave acceleration of auroral electrons, magnetic reconnection and turbulent processes in Earth's magnetosphere and the solar corona, the formation and evolution of astrophysical jets, particle acceleration in cosmic gamma-ray bursts, and dynamo processes creating planetary/galactic magnetic field structures. Specific examples included 1) large-scale plasma simulation codes that are applied to the study of space weather; 2) the Large Plasma Device (LAPD) at the Basic Plasma Science Facility (BaPSF) at the University of California, Los Angeles, which enables controlled studies of Alfvén waves that carry energy and momentum from the sun to Earth and throughout the universe; 3) the Magnetic Reconnection Experiment (MRX) at the Princeton Plasma Physics Laboratory (PPPL), which permits laboratory studies of magnetic reconnection and particle energization processes in Earth's magnetotail and solar flares; and 4) the Max Planck–Princeton Center for Plasma Physics, established in 2012 in partnership with the Max Planck Society in Germany, which specifically explores the application of plasma science to astrophysical problems and their connections to fusion science. In addition, FES sponsored unmagnetized plasma research, such as increased understanding of the role of dusty plasmas in planetary rings and interstellar media, the properties of plasmas created by hypervelocity impacts, and the properties of warm dense matter similar to that found in planetary cores.

SC also funds the development of experimental techniques of fundamental physics that NASA uses in space to investigate high-priority national science objectives. Examples of these efforts include the Alpha Magnetic Spectrometer (AMS) and the Fermi Gamma-ray Space Telescope (FGST). The AMS, also designated AMS-02, is a particle physics experiment designed and built with the support of DOE and international partners. Launched on Space Shuttle Endeavour on mission STS-134 in May 2011 and mounted on the International Space Station (ISS), AMS searches for various types of unusual matter in the cosmos through its exquisite accuracy in the measurement of cosmic rays. AMS science goals include a search for evidence of dark matter and cosmic domains of antimatter, as well as for novel features in cosmic-ray spectra. A Memorandum of Understanding (MOU) signed between

DOE and NASA defined NASA's responsibilities to include provision of power, data handling, and other services on the ISS, while DOE's responsibilities would include experiment operation and data analysis. An unexplained structure discovered by AMS in April 2015 in positron and antiproton cosmic-ray spectra hinted at the existence of dark matter; scientists hope that further data may confirm or deny this hypothesis. The Large Area Telescope (LAT), the primary instrument on NASA's FGST, is a particle physics detector in space to study the gamma-ray sky for high-energy acceleration mechanisms generated by supermassive black holes and supernovae and search for dark matter. SC managed the LAT fabrication and now operates the LAT Science Operations Center. In 2015, FGST published limits from six years of data on dark matter abundances in dwarf spheroidals.

SC also made crucial contributions to the European Space Agency (ESA)–NASA Planck cosmic microwave background satellite mission. Planck measures the cosmic microwave background, which allows studies of the inflationary epoch in the early universe, as well as dark energy, dark matter, and neutrino properties. A Memorandum of Agreement (MOA) signed between NASA and DOE provided dedicated National Energy Research Supercomputing Center (NERSC) computing resources for the Planck mission.

SC and NASA also engaged in many collaborative research efforts in the area of atmospheric science and environmental phenomena. In 2015, SC's Atmospheric Radiation Measurement Climate Research Facility (ARM) activity provided support for the Plains Elevated Convection at Night (PECAN) experiment, which was a joint field campaign between NASA, DOE, the National Science Foundation, and the National Oceanic and Atmospheric Administration (NOAA) with the goal of improving the understanding and simulation of the processes that initiate and maintain convection and convective precipitation at night over the central portion of the U.S. Great Plains. ARM also deployed a mobile measurement facility and research aircraft for CalWater2015, a joint field campaign with NOAA and NASA to study processes associated with atmospheric rivers, which provide a large percentage of winter precipitation on the U.S. West Coast.

During FY 2015, SC's ARM and Terrestrial Ecosystem Science (TES) activities supported aircraft measurements of atmospheric trace gases in Oklahoma and Alaska to improve understanding of the influence of atmospheric and

terrestrial processes on atmospheric carbon dioxide concentrations. DOE coordinated flights with the NASA Tropospheric Emission Sounder and Orbiting Carbon Observatory 2 (OCO-2) for the testing of carbon dioxide retrievals. ARM and TES also provided support for ground-based measurements of carbon dioxide in Oklahoma and Manacapuru, Brazil, in 2015 as part of the Total Column Carbon Observing Network (TCCON), which will be used to validate NASA's OCO-2 satellite. SC's ARM activity included support for two sites (Southern Great Plains and Barrow, Alaska) that host measurement instrumentation providing validation of the Cross-track Infrared Sounder and Advanced Microwave Sounder, intended to fly on NASA's National Polar-orbiting Operational Environmental Satellite System (NPOESS) satellite and to provide profiles of temperature and moisture. The TES activity also supported nine university awards through the interagency Carbon Cycle Science topic of the 2014 NASA Research Opportunities in Space and Earth Sciences (ROSES) solicitation, which closed in FY 2015. SC's Next Generation Ecosystem Experiment (NGEE)–Arctic coupled real-time, ground-based measurements of soil moisture, temperature, carbon dioxide (CO_2), and methane (CH_4) flux while the NASA Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE) collected airborne measurements over Barrow, Alaska. SC's NGEE-Arctic scientists also participated in the science definition team for the upcoming NASA Arctic-Boreal Vulnerability Experiment (ABoVE). Through interagency agreements, SC's Atmospheric System Research (ASR) activity also supported collaboration with NASA scientists on studies using ARM and NASA observations to investigate aerosol and cloud processes and their role in Earth's energy balance.

SC has been working with NASA in a couple of areas to help support NASA's mission interests in this area of concern, and the office provides user facilities for the scientific community, including particle accelerators and ion beams for biological and electronic systems radiation studies. The NASA Space Radiation Laboratory (NSRL), a leading facility for radiobiology studies in the United States, was established at DOE's Brookhaven National Laboratory (BNL) to study the radiobiological effects of using beams of heavy ions (extracted from BNL's Booster accelerator) that are also produced to deliver into SC's Relativistic Heavy Ion Collider (RHIC) facility. An upgrade mutually beneficial to both NSRL and RHIC, and jointly funded by NASA and DOE, was the construction of an Electron Beam Ion Source

(EBIS). The newly commissioned EBIS at BNL significantly extends the range of ion species available for both radiological effects research and fundamental nuclear science, advancing the NASA and SC missions. Electronics space-radiation effects testing that is necessary for mission assurance occurs at several DOE accelerator facilities, including BNL and the Lawrence Berkeley National Laboratory's 88-inch cyclotron. SC and NASA, along with other stakeholders, are planning to jointly participate in supporting a National Academy Study focused on a comprehensive assessment of the future needs of the electronics space-radiation effects testing program in the United States. SC also supports fundamental research on nuclear reactions of astrophysical interest, contributing to SC-NASA mutual interests in the knowledge of stellar evolution and the composition of interstellar space. In addition, since FY 2001, DOE and NASA have engaged in coordinated efforts to better understand and predict the health risks associated with exposure to low-dose radiation. SC's Low Dose Radiation Research Program has coordinated with NASA's Space Radiation Project within NASA's Human Research Program. The SC Low Dose program focuses on doses of radiation measured at or below current workplace exposure limits; current collaborations are limited due to a decreasing emphasis on human radiation research within SC's research portfolio.

Office of Nuclear Energy

The Office of Nuclear Energy supports NASA's planetary science and human exploration programs by maintaining capabilities to develop, produce, and deliver radioisotope power systems (RPSs) and fission power and propulsion system technology development efforts for Federal user agencies, such as NASA. The RPS infrastructure capabilities, funded by NASA and managed by NE, support NE's production of RPSs for current space mission applications.

NE and its predecessors have provided RPSs that have safely enabled deep space exploration and national security missions for over five decades. The RPSs convert the heat from the natural radioactive decay of plutonium (Pu)-238 into electricity. RPSs reliably operate for decades under the harsh conditions encountered in deep space or on the surfaces of other planets.

NE continued work on the next RPS-powered mission, a Mars rover mission to launch in 2020. NE worked on producing the MMRTG and preparing the Safety Analysis Reports to support the nuclear launch approval processes. With NASA funding support, NE also worked on making enhancements to the current RPS production infrastructure by upgrading equipment for more robust operations. In FY 2014, continuing technical issues with the Advanced Stirling Radioisotope Generator (ASRG) system resulted in NASA's termination of the project for budgetary reasons. NE completed its closeout of the ASRG project this year. NE and NASA continued to investigate advances in both thermoelectric and Stirling power conversion technologies that could result in more efficient and capable RPSs for NASA's long-term exploration goals. Advanced thermoelectric technology developed by NASA JPL showing promising benefits has been transferred to private industry for final development and manufacturing feasibility. DOE and NASA partnered to review the technology for potential insertion into the MMRTG system as a future system advancement.

NE continued working with NASA to re-establish domestic Pu-238 production at existing facilities, the Oak Ridge National Laboratory and Idaho National Laboratory, in order to ensure continued availability of RPS power systems for future science missions, a project that began in FY 2011 and is fully funded by NASA. In 2015, the project began the first end-to-end demonstration of chemical processing steps needed to recover Pu-238 from irradiated targets.

NE and DOE national laboratories provide key support in the areas of reactor modeling, as well as fuel development and qualification, for NASA's Nuclear Cryogenic Propulsion Stage project, commonly known as Nuclear Thermal Propulsion (NTP). In 2015, the project successfully fabricated and heat-treated a graphite composite fuel element. Fabrication of the composite fuel element represented a significant step in re-establishing the fabrication processes used on previous NTP programs.

This page is intentionally left blank.

Smithsonian Institution

The Smithsonian Institution continued to contribute to national aerospace goals through the activities of the Smithsonian Astrophysical Observatory (SAO). Together, SAO and the Harvard College Observatory form the Harvard-Smithsonian Center for Astrophysics (CfA) in Cambridge, Massachusetts. Through this organization, more than 300 scientists engaged in a broad program of research in astronomy, astrophysics, Earth and space sciences, and science education. The Smithsonian National Air and Space Museum (NASM) in Washington, DC, also contributed to national aerospace goals through its research and education activities.

Planetary discoveries continued to dominate the news coming from SAO in FY 2015. At a January press conference, astronomers announced that they had found eight new planets orbiting in the "Goldilocks" zone of their stars. This zone, also known as the habitable zone, is the distance where temperatures are warm enough for liquid water to exist on a planet's surface. In addition, scientists showed that rocky exoplanets, or planets orbiting distant stars, share a similar composition with Earth and that rocky exoplanets larger than Earth (known as super-Earths) can host long-lived oceans lasting billions of years. Astronomers also pinpointed the closest rocky planet to Earth that transits, or crosses the face of, its star. At a distance of only 21 light-years, the planet is likely to be a favorite target for next-generation telescopes.

Beyond our cosmic neighborhood, SAO researchers spotted 11 runaway galaxies that have been flung from their homes to wander the void of intergalactic space. These galaxies, traveling at speeds of more than six million miles per hour, face a lonely future exiled from the galaxy clusters they used to live in.

NASA's Spitzer Space Telescope continued to produce exciting new views of the universe at infrared wavelengths. Spitzer is the fourth and final space telescope in NASA's Great Observatory series. Spitzer's Infrared Array Camera (IRAC) was developed at SAO and constructed at NASA's Goddard Space Flight Center. SAO scientists, in collaboration with the Spitzer Science Center, continue to play an important role in the operation of IRAC, the data analysis, and its use for astronomical observations.

In FY 2015, SAO scientists completed and made publicly available an infrared source catalog based on the Spitzer-Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey (S-CANDELS), a survey that was designed to detect numerous galaxies in the very early universe. S-CANDELS looked at five widely separated areas that had also been studied by the Hubble Space Telescope. Altogether, the survey examined 0.16 square degrees of the sky and detected approximately 135,000 galaxies as faint as 26th magnitude. Combined with the Hubble observations, this survey has identified some of the earliest galaxies in the universe and will be an important source of objects for future spectroscopic observations with the James Webb Space Telescope.

SAO scientists also made the first detection from the Spitzer Space Telescope of the infrared (4.5-micron-wavelength) variability of Sagittarius A* (A-star), the emitting source associated with the Milky Way's central massive black hole. The objective of this study was to understand how a massive black hole feeds on the gas and dust disk surrounding it. Spitzer's Infrared Array Camera obtained an approximately 23-hour continuous light curve, more than two times longer than any previous infrared observation. Scientists saw pulsed emission above the noise level about one-third of the time. The results also characterized the variability of Sagittarius A* prior to the closest approach of the tidally deformed object named G2, a putative infalling gas cloud that orbits close to Sagittarius A*. Scientists did not see evidence in the light curve for any activity attributable to the G2 cloud interaction at the observing epoch, which was ~100 days before the expected closest passage.

The Chandra X-ray Observatory continues to play an important role in the exploration of the universe. With its unrivaled ability to create high-resolution x-ray images, Chandra has enabled astronomers to investigate phenomena as diverse as

comets, black holes, dark matter, and dark energy. The Smithsonian Astrophysical Observatory controls science and flight operations from the Chandra X-ray Center at its location in Cambridge, Massachusetts.

During FY 2015, astronomers used Chandra to observe the largest x-ray flare ever detected from Sagittarius A*, raising questions about the behavior of this giant black hole and its surrounding environment. In a separate finding by another group of researchers, Chandra provided evidence that Sagittarius A* may be producing mysterious particles called neutrinos. If confirmed, this would be the first time that scientists have traced neutrinos back to a black hole.

In June 2015, researchers published Chandra's discovery of the largest and brightest set of rings from x-ray light echoes ever observed. These extraordinary rings, produced by an intense flare from a neutron star, provided astronomers with a rare chance to determine how far across the Milky Way Galaxy the star is from Earth.

Also during this period, astronomers announced that by combining observations from Chandra and the Hubble Space Telescope, they found that dark matter does not slow down when colliding with itself. This means that dark matter interacts with itself less than previously thought. Researchers say this finding narrows down the options for what dark matter, an invisible matter that makes up most of the mass of the universe, might be.

The Solar Dynamics Observatory provides better-than-HD-quality images of the sun's surface and outer atmosphere. SAO is a major partner in the Atmospheric Imaging Assembly (AIA)—a group of four telescopes that photograph the sun in ten different wavelength bands, or colors, once every 12 seconds.

The Hinode mission is a joint U.S.-Japan-Europe mission designed to study the detailed physics of the sun's atmosphere. SAO is the lead institution on the X-Ray Telescope (XRT) on the Hinode spacecraft. The XRT is a telescope that images energetic x-rays that are produced in the hottest parts of the sun's corona.

In FY 2015, AIA and Hinode XRT observations formed the basis of new computer models of the sun's magnetic field. These models show how magnetic energy is stored in the corona and which conditions are needed to release the energy quickly in flares and coronal mass ejections.

NASA's Interface Region Imaging Spectrograph (IRIS) satellite provided a new view of the sun's mysterious chromosphere and transition regions. SAO built the

telescope feed and has an active role in IRIS operations, calibration, and science. IRIS is providing information on particle acceleration in hot coronal loops, allowing us to better understand the physical processes in solar flares.

In public outreach, SAO continued its popular monthly Observatory Night lectures and observing sessions. Begun by observatory director Harlow Shapley in 1930, these public nights offer the local community an opportunity to learn about the latest advances in astronomy and view the moon, stars, and planets through a variety of telescopes.

SAO also hosted a special program on July 14, the day that NASA's New Horizons spacecraft flew past Pluto. A full crowd watched and waited for NASA to receive a signal from the probe showing that it had survived the encounter and captured data.

An even larger crowd visited the observatory on September 26 to witness a total eclipse of the moon. Approximately 700 people viewed the lunar eclipse through rooftop telescopes. This event, the last total lunar eclipse until 2018, proved especially photogenic. SAO distributed pictures from attendees online and in its e-mail newsletter.

Also in FY 2015, "The Dynamic Sun," a new exhibit conceived, designed, and built by SAO researchers, opened at the Smithsonian's National Air and Space Museum in Washington, DC. It featured a giant video wall intended to create a visceral impact and show visitors how an ever-changing sun affects Earth. The exhibit combined six 50-inch monitors to create a 7- by 6-foot field of view displaying images from AIA, which takes images of the full sun's atmospheric layers every 12 seconds with an image size of 4,096 × 4,096 pixels. By comparison, a high-definition TV can display only 1,920 × 1,080 pixels. "The Dynamic Sun" is expected to remain on display through 2019.

In FY 2015, NASM continued to educate and inspire the public through exhibits, research, and education programs, including discovery stations; lecture series; family educational events; publications; science, technology, engineering, and mathematics (STEM) Webcasts; and intern training. The annual Exploring Space Lecture Series focused on the 25th anniversary of the Hubble Space Telescope, with presentations on the significant technology, history, and science of this remarkable instrument. McGraw-Hill published a new edition of the book *Introduction*

to Flight, a noted resource on aeronautical and aerospace engineering, in 2015. In January, NASM opened the new exhibition "Outside the Spacecraft: 50 Years of Extra-Vehicular Activity" on the history and technology of extravehicular activities (EVAs). NASM's Exploring the Planets gallery presented two new exhibits, one called "Three Generations of Mars Rovers" and another on the New Horizons mission to Pluto, which showcases a full-scale model of the spacecraft and brings the latest images of Pluto and its moons to the public. "Above and Beyond," a highly interactive and hands-on temporary exhibit, showcases aerospace technology.

NASM added several significant collections to its holdings this year. The Sir Arthur C. Clarke Collection contains papers of the noted science and science fiction writer and should be a fascinating resource for researchers. The Sally K. Ride Collection includes papers and objects from the estate of the first U.S. woman in space. The Evelyn Way Kendall Ballooning and Early Aviation Collection contains rare art, books, photos, and manuscripts relating to the history of flight from the 18th to early 20th centuries.

Staff members in NASM's Center for Earth and Planetary Studies (CEPS) continued to participate in the science teams of several spacecraft missions. Dr. John Grant is a participating scientist for the Mars Exploration Rover (MER) mission that is currently operating on Mars. He is a chair of the MER Science Operations Working Group, and in that capacity, he leads day-to-day science planning for the Opportunity rover. In addition, he is cochair of the Mars 2020 Landing Site Steering Committee. CEPS staff members also serve on the science teams for the Mars Science Laboratory (MSL), the Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS) instrument on Mars Express, both the High Resolution Imaging Science Experiment (HiRISE) and Shallow Subsurface Radar (SHARAD) instruments on the Mars Reconnaissance Orbiter (MRO), the radar sounder on ESA's Jupiter Icy Moons Explorer (JUICE), the Lunar Reconnaissance Orbiter (LRO), the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft, and the Europa Mission. CEPS continued its active research program in planetary and terrestrial geology and geophysics with research on such topics as comparative planetology; Martian fluvial, aeolian, and volcanic features; and radar studies of the moon, Mercury, and Mars.

This page is intentionally left blank.

APPENDICES

Appendix A-1

U.S. Government Spacecraft Record

(Includes spacecraft from cooperating countries launched by U.S. launch vehicles.)

	Earth Orbit[a]		Earth Escape[b]	
Calendar Year	Success	Failure	Success	Failure
1957	0	1	0	0
1958	5	8	0	4
1959	9	9	1	2
1960	16	12	1	2
1961	35	12	0	2
1962	55	12	4	1
1963	62	11	0	0
1964	69	8	4	0
1965	93	7	4	1
1966	94	12	7	1[b]
1967	78	4	10	0
1968	61	15	3	0
1969	58	1	8	1
1970	36	1	3	0
1971	45	2	8	1
1972	33	2	8	0
1973	23	2	3	0
1974	27	2	1	0
1975	30	4	4	0
1976	33	0	1	0
1977	27	2	2	0
1978	34	2	7	0
1979	18	0	0	0
1980	16	4	0	0
1981	20	1	0	0
1982	21	0	0	0
1983	31	0	0	0
1984	35	3	0	0
1985	37	1	0	0
1986	11	4	0	0
1987	9	1	0	0
1988	16	1	0	0
1989	24	0	2	0
1990	40	0	1	0
1991	32[c]	0	0	0
1992	26[c]	0	1	0
1993	28[c]	1	1	0
1994	31[c]	1	1	0
1995	24[c, d]	2	1	0
1996	30	1	3	0
1997	22[e]	0	1	0
1998	23	0	2	0
1999	35	4	2	0
2000	31[f]	0	0	0
2001	23	0	3	0
2002	18	0	0	1[b]
2003	28[c, f]	0	2	0
2004	8[c]	0	1	0
2005	10	0	2	0
2006	20[d]	0	2	0
2007	16	2	2	0
2008	22[f]	0	0	0
2009	24[f]	1	0	0
2010	15	0	0	0
2011	16	1	3	0
2012	13	0	0	0
2013	18	0	1	0
2014	22	1	0	0
2015 (through September 30, 2015)	12	1	1	0
TOTAL	**1,748**	**159**	**111**	**16**

a. The criterion of success or failure used is attainment of Earth orbit or Earth escape rather than judgment of mission success. "Escape" flights include all that were intended to go to at least an altitude equal to lunar distance from Earth.
b. This Earth-escape failure did attain Earth orbit and, therefore, is included in the Earth-orbit success totals.
c. This excludes commercial satellites. It counts separately spacecraft launched by the same launch vehicle.
d. This counts various sets of microsatellites as a single payload.
e. This includes the Small Spacecraft Technology Initiative (SSTI) Lewis spacecraft that began spinning out of control shortly after it achieved Earth orbit.
f. This includes American spacecraft not launched in the U.S.

Appendix A-2

World Record of Space Launches Successful in Attaining Earth Orbit or Beyond

(Enumerates launches rather than spacecraft; some launches orbited multiple spacecraft.)[a]

Calendar Year	United States[b]	USSR/ CIS	France[c]	Italy[c]	Japan	People's Republic of China	Australia	United Kingdom[c]	European Space Agency	India	Israel	Iran	North Korea	South Korea
1957		2												
1958	5	1												
1959	10	3												
1960	16	3												
1961	29	6												
1962	52	20												
1963	38	17												
1964	57	30												
1965	63	48	1											
1966	73	44	1											
1967	57	66	2	1			1							
1968	45	74												
1969	40	70												
1970	28	81	2	1	1	1								
1971	30	83	1	2	2	1		1						
1972	30	74		1	1									
1973	23	86												
1974	22	81		2	1									
1975	27	89	3	1	2	3								
1976	26	99			1	2								
1977	24	98			2									
1978	32	88			3	1								
1979	16	87			2				1					
1980	13	89			2					1				
1981	18	98			3	1			2	1				
1982	18	101			1	1								
1983	22	98			3	1			2	1				
1984	22	97			3	3			4					
1985	17	98			2	1			3					
1986	6	91			2	2			2					
1987	8	95			3	2			2					
1988	12	90			2	4			7					
1989	17	74			2				7		1			
1990	27	75			3	5			5		1			
1991	20	62			2	1			9	1				
1992	31	55			2	3			7	2				
1993	24	45			1	1			7					
1994	26	49			2	5			6	2				
1995	27	33			1	2			12		1			
1996	32	25			1	3			10	1				
1997	37	28			2	6			12	1				
1998	34	24			2	6			11					
1999	32	26				4			10	1				
2000	30	34				5			12					
2001	23	23			1	1			8	2				
2002	18	23			3	4			11	1	1			
2003	26	21			2	6			4	2				
2004	19	22				8			3	1				
2005	16	26			2	5			5	1				
2006	15	16			5	3			5					
2007	25	33			3	13			8	3	1			
2008[d]	19	26			1	11			7	3				
2009	25	29			3	4			9	4		1		
2010	15	30			2	15			6	1	1			
2011	17	33			3	18			7	3		1		
2012	13	27			2	19			10	2		1	1	
2013[e]	19	29			3	14			7	3				1
2014[e]	22	31			4	16			10	4	1			
2015*	13	16			3	9			8	4		1		
*(through September 30, 2015)														
TOTAL	**1,501**	**3,022**	**10**	**8**	**91**	**210**	**1**	**1**	**239**	**45**	**7**	**4**	**1**	**1**

a. This includes commercial expendable launches and launches of the Space Shuttle as well as launches to useless orbit.
b. Launches from U.S.-Russia joint platform included in U.S. totals.
c. Since 1979, all launches for ESA member countries have been joint and are listed under ESA.
d. Since 2008, the ESA statistics include the Soyuz launches from Guiana Space Centre.
e. The data published in the FY 2014 report reflect incorrect totals and have been adjusted.

Appendix B
SUCCESSFUL LAUNCHES TO ORBIT ON U.S. VEHICLES

October 1, 2014–September 30, 2015

Launch Date Spacecraft Name COSPAR* Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
October 29, 2014 Navstar 72 GPS 2F-8 2014-068A Atlas 5-401	Navigation	20,525 20,473 730.3 55.0	U.S. Air Force, combined military/civilian Global Positioning System
December 5, 2014 Orion EFT-1 2014-077A Delta 4 Heavy	Test flight	882 187 95.3 28.8	Exploration Flight Test 1 (EFT-1)
December 13, 2014 NROL 35 (USA 259) 2014-081A Atlas 5-541	Military/communications	37,420 2,109 701.1 62.8	U.S. National Reconnaissance Office, probably including electronic intelligence gathering and missile launch detection using Space-Based Infrared System (SBIRS)
January 10, 2015 Dragon CRS-5 2015-001A Falcon 9 v1.1	International Space Station	407 399 92.63 51.65	Cargo resupply
January 21, 2015 MUOS 3 2015-002A Atlas 5-551	Military/communications	35,900 35,800 1,436.1 Not available	Mobile User Objective System (MUOS) for the U.S. Navy
January 31, 2015 SMAP 2015-003A Delta 2-7320	Earth science	683 681 98.4 98.12	Soil Moisture Active Passive (SMAP) satellite Also carried CubeSats: FIREBIRD 3 (Focused Investigations of Relativistic Electron Burst Intensity, Range, and Dynamics), FIREBIRD 4, and ExoCube
February 11, 2015 DSCOVR 2015-007A Falcon 9 v1.1	Earth observation/space weather	Lagrange Point 1 (L1)	Deep Space Climate Observatory (DSCOVR), formerly known as Triana
March 2, 2015 Eutelsat 115 West B 2015-010B Falcon 9 v1.1	Communications	35,788 35,786 1,436.1 0.05	Also launched ABS 3A for Asia Broadcast Satellite
March 13, 2015 MMS 1-4 2015-011A-D Atlas 5-421	Space physics	70,091 1,373 1,433.3 28.79	Magnetospheric Multiscale (MMS) mission Note: Orbital statistics reflect MMS 1
March 25, 2015 Navstar 73 GPS 2F-9 2015-013A Delta 4M+4,2	Navigation	20,197 20,167 717.98 55.04	U.S. Air Force
April 14, 2015 Dragon CRS-6 2015-021-A Falcon 9 v1.1	International Space Station	404 399 92.6 51.64	Cargo resupply
April 27, 2015 TurkmenAlem 52E 2015-023A Falcon 9 v1.1	Communications	35,799 35,774 1,432.11 0.01	Launched on behalf of Turkmenistan

* U.N. Committee on Space Research

Appendix B (cont.)

Successful Launches to Orbit on U.S. Vehicles

October 1, 2014–September 30, 2015

Launch Date Spacecraft Name COSPAR* Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
May 20, 2015 OTV4 X37B (AFSPC 5) 2015-025A Atlas 5-501	Military/communications	322 309 90.83 38	U.S. Air Force Also carried Opticube 01-03, Parkinson Satellite (Psat), Ballistic Reinforced Communication Satellite (BRICSat-P), Globalstar Experiment And Risk Reduction Satellite Flight Experiment (GEARRSAT), Aerocube 8A-B, and LightSail-A
July 15, 2015 Navstar 74 GPS 2F-10 2015-033A Atlas 5-401	Navigation	20,230 20,133 717.95 55.08	U.S. Air Force
July 24, 2015 WGS 7 (USA 263) 2015-036A Delta 4M+5,4	Military/communications	36,000 36,000 1,436 0	Department of Defense
September 2, 2015 MUOS 4 2015-044A Atlas 5-551	Military/communications	Geostationary orbit	Mobile User Objective System (MUOS) for the U.S. Navy

Appendix C
HUMAN SPACEFLIGHTS

October 1, 2014–September 30, 2015

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Soyuz TMA 15M (Expedition 42)	November 23, 2014	Samantha Cristoforetti Anton Shkaplerov Terry Virts	199:17:42	Began spacewalks for a major reconfiguration of the exterior of the International Space Station to prepare Commercial Crew Vehicles Installed the Common Communications for Visiting Vehicles (C2V2) communications system Automated Transfer Vehicle (ATV) 5 completed the final mission of the ATV series and destructive reentry into the atmosphere on February 14, 2015
Soyuz TMA-16M (Expedition 43)	March 27, 2015	Scott Kelly Mikhail Kornienko Gennady Padalka	168:5:9	Began the One-Year Mission including medical, psychological, and biomedical studies with NASA astronaut Scott Kelly and Roscosmos cosmonaut Mikhail Kornienko Began the Twins Study with NASA astronaut Scott Kelly (in space) and his brother, former astronaut Mark Kelly (on Earth) Moved the Permanent Multipurpose Module from Node 1 to Node 3, which allows docking for two cargo vehicles Loss of Progress M-27M on April 28, 2015 Dragon SpX-7/Falcon 9 rocket failure on June 28, 2015
Soyuz TMA-17M (Expedition 44)	July 22, 2015	Kjell Lindgren Oleg Kononenko Kimiya Yui	Not available	Cosmonaut Gennady Padalka set a new record for time in space (168 days for this mission, 879 total days in space) Ate lettuce from Veggie, a plant growth system onboard
Soyuz TMA-18M (Expedition 45)	September 2, 2015	Aidyn Aimbetov Andreas Mogensen Sergey Volkov	Not available	Marked 15 years of Station occupation since November 2, 2000 Returned Soyuz TMA-16M to Earth

Appendix D-1A

SPACE ACTIVITIES OF THE U.S. GOVERNMENT

HISTORICAL TABLE OF BUDGET AUTHORITY

(in millions of real-year dollars)

FY	NASA Total	NASA Space	DOD[a]	Other[b]	DOE[c]	DOC	DOI	USDA	NSF[d]	DOT	Total Space
1959	331	261	490	34	34						785
1960	524	462	561	43	43						1,066
1961	964	926	814	68	68						1,808
1962	1,825	1,797	1,298	199	148	51					3,294
1963	3,673	3,626	1,550	257	214	43					5,433
1964	5,100	5,016	1,599	213	210	3					6,828
1965	5,250	5,138	1,574	241	229	12					6,953
1966	5,175	5,065	1,689	214	187	27					6,968
1967	4,966	4,830	1,664	213	184	29					6,707
1968	4,587	4,430	1,922	174	145	28	0.2	1			6,526
1969	3,991	3,822	2,013	170	118	20	0.2	1	31		6,005
1970	3,746	3,547	1,678	141	103	8	1	1	28		5,366
1971	3,311	3,101	1,512	162	95	27	2	1	37		4,775
1972	3,307	3,071	1,407	133	55	31	6	2	39		4,611
1973	3,406	3,093	1,623	147	54	40	10	2	41		4,863
1974	3,037	2,759	1,766	158	42	60	9	3	44		4,683
1975	3,229	2,915	1,892	158	30	64	8	2	54		4,965
1976	3,550	3,225	1,983	168	23	72	10	4	59		5,376
TQ*	932	849	460	43	5	22	3	1	12		1,352
1977	3,818	3,440	2,412	194	22	91	10	6	65		6,046
1978	4,060	3,623	2,738	226	34	103	10	8	71		6,587
1979	4,596	4,030	3,036	248	59	98	10	8	73		7,314
1980	5,240	4,680	3,848	231	40	93	12	14	72		8,759
1981	5,518	4,992	4,828	234	41	87	12	16	78		10,054
1982	6,044	5,528	6,679	313	61	145	12	15	80		12,520
1983	6,875	6,328	9,019	327	39	178	5	20	85		15,674
1984	7,458	6,858	10,195	395	34	236	3	19	103		17,448
1985	7,573	6,925	12,768	584	34	423	2	15	110		20,277
1986	7,807	7,165	14,126	477	35	309	2	23	108		21,768
1987	10,923	9,809	16,287	466	48	278	8	19	112	1	26,562
1988	9,062	8,322	17,679	741	241	352	14	18	115	1	26,742
1989	10,969	10,097	17,906	560	97	301	17	21	121	3	28,563
1990	12,324	11,460	15,616	506	79	243	31	25	124	4	27,582
1991	14,016	13,046	14,181	772	251	251	29	26	211	4	27,999
1992	14,317	13,199	15,023	798	223	327	34	29	181	4	29,020
1993	14,310	13,064	14,106	731	165	324	33	25	180	4	27,901
1994	14,570	13,022	13,166	632	74	312	31	31	179	5	26,820
1995	13,854	12,543	10,644	759	60	352	31	32	278	6	23,946
1996	13,884	12,569	11,514	828	46	472	36	37	231	6	24,911
1997	13,709	12,457	11,727	789	35	448	42	39	219	6	24,973
1998	13,648	12,321	12,359	839	103	435	43	39	213	6	25,519
1999	13,653	12,459	13,203	982	105	575	59	37	200	6	26,644
2000	13,601	12,521	12,941	1,056	164	575	60	44	207	6	26,518
2001	14,230	13,304	14,326	1,062	145	577	60	36	232	12	28,692
2002	14,868	13,871	15,740	1,180	166	644	64	28	266	12	30,791
2003	15,364	14,360	19,388	1,305	191	649	74	42	337	12	35,053
2004	15,379	14,322	19,115	1,464	209	745	71	61	366	12	34,901
2005	16,198	15,234	19,690	1,551	229	807	70	73	360	12	36,475
2006	16,623	15,765	22,114	1,647	245	860	82	84	364	12	39,526
2007	16,285	15,568	22,418	1,680	200	912	87	65	404	12	39,666
2008	17,117	16,502	24,795	1,698	195	862	90	59	479	13	42,995
2009	17,775	17,275	26,528	1,868	200	1,078	64	27	485	14	45,671
2010	18,725	18,228	26,463	2,057	203	1,261	67	27	484	15	46,748
2011	18,432	17,898	27,234	2,186	229	1,444	66	20	412	15	47,318
2012	17,773	17,203	26,677	2,580	199	1,876	76	7	406	16	46,460
2013	17,395	16,865	10,818	2,578	185	1,865	84	20	409	15	30,261
2014	17,647	17,081	10,400	2,839	174	2,087	82	19	461	16	30,320
2015	18,010	17,359	10,325	3,010	182	2,223	83	19	485	18	30,694

a. DOD reported that improvements to the estimating methodology resulted in a change in estimated budget authority and outlays starting in FY 2013.

b. The Other column is the total of the non-NASA and non-DOD budget authority figures that appear in the succeeding columns. The total is sometimes different from the sum of the individual figures because of rounding. The Total Space column does not include the NASA Total column because the latter includes budget authority for aeronautics as well as space. For the years 1989–97, this Other column also includes small figures for the Environmental Protection Agency (EPA), as well as $2.1 billion for the replacement of Space Shuttle Challenger in 1987.

c. DOE has recalculated its space expenditures since 1998.

d. The NSF has recalculated its space expenditures since 1980, making them significantly higher than reported in previous years.

* Transition Quarter

Appendix D-1B

SPACE ACTIVITIES OF THE U.S. GOVERNMENT

HISTORICAL TABLE OF BUDGET AUTHORITY

(in millions of inflation-adjusted FY 2015 dollars)

FY	Inflation Factors	NASA Total	NASA Space	DOD[a]	Other[b]	DOE[c]	DOC	DOI	USDA	NSF[d]	DOT	Total Space
1959	6.391	2,116	1,668	3,132	217	217						5,017
1960	6.295	3,298	2,908	3,531	271	271						6,710
1961	6.208	5,984	5,749	5,053	422	422						11,224
1962	6.124	11,175	11,004	7,948	1,219	906	312					20,171
1963	6.062	22,265	21,980	9,396	1,558	1,297	261					32,933
1964	5.988	30,538	30,035	9,575	1,275	1,257	18					40,885
1965	5.916	31,057	30,395	9,311	1,426	1,355	71					41,132
1966	5.814	30,087	29,447	9,820	1,244	1,087	157					40,511
1967	5.691	28,264	27,490	9,471	1,212	1,047	165					38,172
1968	5.523	25,333	24,466	10,615	962	801	155	1	6			36,042
1969	5.340	21,312	20,409	10,749	910	630	107	1	5	166		32,068
1970	5.105	19,125	18,109	8,567	720	526	41	5	5	143		27,395
1971	4.844	16,040	15,023	7,325	785	460	131	10	5	179		23,132
1972	4.611	15,248	14,160	6,488	615	254	143	28	9	182		21,263
1973	4.401	14,989	13,611	7,142	648	238	176	44	9	182		21,402
1974	4.219	12,812	11,639	7,450	667	177	253	38	13	186		19,756
1975	3.939	12,718	11,482	7,452	621	118	252	32	8	212		19,555
1976	3.571	12,675	11,515	7,080	601	82	257	36	14	212		19,196
TQ*	3.339	3,112	2,835	1,536	144	17	73	10	3	40		4,514
1977	3.242	12,377	11,152	7,819	627	71	295	32	19	209		19,598
1978	3.115	12,646	11,285	8,528	704	106	321	31	25	221		20,516
1979	2.918	13,411	11,759	8,859	724	172	286	29	23	213		21,342
1980	2.701	14,155	12,642	10,395	624	108	251	32	38	195		23,661
1981	2.485	13,710	12,403	11,996	582	102	216	30	40	194		24,981
1982	2.263	13,680	12,512	15,118	708	138	328	27	34	180		28,338
1983	2.118	14,561	13,403	19,102	693	83	377	11	42	180		33,197
1984	2.029	15,129	13,912	20,681	801	69	479	6	39	208		35,393
1985	1.959	14,838	13,569	25,018	1,144	67	829	4	29	215		39,730
1986	1.896	14,806	13,588	26,790	904	66	586	4	44	204		41,282
1987	1.854	20,253	18,188	30,199	864	89	515	15	35	207	2	49,250
1988	1.814	16,436	15,094	32,065	1,344	437	638	25	33	209	2	48,503
1989	1.757	19,274	17,742	31,463	984	170	529	30	37	213	5	50,189
1990	1.690	20,825	19,365	26,388	855	133	411	52	42	209	7	46,608
1991	1.631	22,855	21,274	23,124	1,259	409	409	47	42	344	7	45,657
1992	1.575	22,547	20,786	23,659	1,256	351	515	54	46	285	6	45,701
1993	1.537	21,997	20,082	21,684	1,123	254	498	51	38	276	6	42,889
1994	1.502	21,877	19,553	19,769	950	111	468	47	47	269	8	40,272
1995	1.469	20,358	18,432	15,641	1,115	88	517	46	47	408	9	35,188
1996	1.439	19,978	18,086	16,568	1,191	66	679	52	53	332	9	35,846
1997	1.413	19,366	17,597	16,566	1,115	49	633	59	55	310	8	35,278
1998	1.388	18,945	17,103	17,156	1,165	143	604	60	54	296	8	35,424
1999	1.371	18,721	17,084	18,104	1,347	144	788	81	51	274	8	36,535
2000	1.354	18,416	16,954	17,523	1,429	222	779	81	60	280	8	35,906
2001	1.327	18,878	17,649	19,005	1,409	192	765	80	48	308	16	38,063
2002	1.295	19,259	17,967	20,388	1,528	215	834	83	36	345	16	39,884
2003	1.275	19,586	18,307	24,716	1,664	243	827	94	54	430	15	44,687
2004	1.251	19,238	17,916	23,911	1,831	261	932	89	76	458	15	43,659
2005	1.221	19,773	18,596	24,035	1,893	280	985	85	89	439	15	44,525
2006	1.184	19,674	18,658	26,173	1,949	290	1,018	97	99	431	14	46,780
2007	1.146	18,667	17,845	25,697	1,926	229	1,045	100	75	463	14	45,467
2008	1.116	19,104	18,417	27,673	1,895	218	962	100	66	535	15	47,985
2009	1.093	19,437	18,890	29,008	2,042	219	1,179	70	29	530	15	49,940
2010	1.081	20,238	19,701	28,601	2,223	219	1,363	72	29	523	16	50,525
2011	1.071	19,749	19,177	29,181	2,342	245	1,547	71	21	441	16	50,700
2012	1.051	18,679	18,080	28,036	2,711	209	1,972	80	7	427	17	48,827
2013	1.033	17,967	17,419	10,818	2,663	191	1,926	87	21	422	15	31,256
2014	1.015	17,647	17,081	10,400	2,839	174	2,087	82	19	461	16	30,781
2015	1.000	18,010	17,359	10,325	3,010	182	2,223	83	19	485	18	30,694

a. DOD reported that improvements to the estimating methodology resulted in a change in estimated budget authority and outlays starting in FY 2013.
b. The Other column is the total of the non-NASA and non-DOD budget authority figures that appear in the succeeding columns. The total is sometimes different from the sum of the individual figures because of rounding. The Total Space column does not include the NASA Total column because the latter includes budget authority for aeronautics as well as space. For the years 1989–97, this Other column also includes small figures for the Environmental Protection Agency (EPA), as well as $2.1 billion for the replacement of Space Shuttle Challenger in 1987.
c. The DOE has recalculated its space expenditures since 1998.
d. The NSF has recalculated its space expenditures since 1980, making them significantly higher than reported in previous years.
* Transition Quarter

Appendix D-2

Federal Space Activities Budget

(in millions of dollars by fiscal year)

Federal Agencies	Budget Authority 2013 actual[1]	2014 actual	2015 actual	2016 est.	Budget Outlays 2013 actual	2014 actual	2015 actual	2016 est.
NASA[2]	16,865.2	17,080.5	17,359	18,645	16,989	16,558.7	17,697.4	18,346
DOD[3, 4]	10,818	10,400	10,325	10,333	10,299	9,600	15,895	12,581
DOE	185	174	182	187	183	174	198	204
DOC[5]	1,864.8	2,087.1	2,223.1	2,349.4	1,130.5	1,167.3	1,300.3	1,387.5
DOI[6]	84	82	83	87	81	81	82	87
USDA	19.6	19.3	18.9	18.8	17	18.7	17.3	18.7
DOT	15	16	17.6	21.8	15	16	17.6	21.8
NSF[7]	409	461	485.2	507.7	387	391	444.6	452.8

1. FY 2013 figures incorporate the effect of sequestration.
2. The FY 2015 estimate is based on the prior year's Outlays versus Budget Authority.
3. Does not include Department of Defense (DOD) or Office of the Director of National Intelligence (ODNI) intelligence programs. DOD FY 2014 and FY 2015 figures for Budget Authority and Outlays are estimated at the time of preparing this report. Improvements to the estimating methodology resulted in a change in estimated Budget Authority and Outlays starting in FY 2013.
4. At the time of preparing this report, DOD submitted estimates as billions of dollars, so the figures are rounded to the nearest hundred million.
5. The Budget Outlays columns reflect dollars "costed" in a fiscal year specific to that same fiscal year's appropriated dollars.
6. The numbers for FY 2014 Actual and Outlays are estimates for both satellite and aerial funding.
7. "Actual" = actual obligations.

Appendix D-3

Federal Aeronautics Activities Budget

(in millions of dollars by fiscal year)

	Budget Authority				Budget Outlays			
Federal Agencies	**2013 actual[1]**	**2014 actual**	**2015 actual**	**2016 est.**	**2013 actual**	**2014 actual**	**2015 actual**	**2016 est.**
NASA[2]	529.5	566	651	640	558.4	538.7	578.3	587
USDA	33.1	34.4	26.7	26.8	30.2	32.6	26.7	26.7
DOD[3]	82,730	75,500	50,800	57,600	91,120	75,700	42,885	58,697
DOI[4]	29	31	31	36	28	30	31	36
DOT	2,758	2,744	2,741.8	3,004.9	2,990	2,851	2,761.1	2,895.8

1. FY 2013 figures incorporate the effect of sequestration.
2. The FY 2015 estimate is based on the prior year's Outlays versus Budget Authority.
3. DOD FY 2014 and FY 2015 figures for Budget Authority and Outlays are estimated at the time of preparing this report. Improvements to the estimating methodology resulted in a change in estimated Budget Authority and Outlays starting in FY 2013.
4. At the time of preparing this report, DOD submitted estimates as billions of dollars, so the figures are rounded to the nearest hundred million.
5. The numbers for FY 2014 Actual and Outlays are estimates for both satellite and aerial funding.

Acronyms

3D-MAT	3-Dimensional Multifunctional Ablative Thermal Protection Systems

A

AAFEX	Alternative Aviation Fuel Experiment
ABoVE	Arctic-Boreal Vulnerability Experiment
ABS	Asia Broadcast Satellite
ACCESS	Alternative Fuel Effects on Contrails and Cruise Emissions
ACE	Advanced Composition Explorer
ACEC	Area of Critical Environmental Concern
ACES	Atomic Clock Ensemble in Space
ACT	Atacama Cosmology Telescope
ACTPol	ACT Polarimeter
ADP	Acoustic Doppler Profiler
ADS-B	Automatic Dependent Surveillance–Broadcast
AE	Archive Explorer
AEFS	Advanced Electronic Flight Strips
AEHF	Advanced Extremely High Frequency
AES	Advanced Exploration Systems
AFIT	Air Force Institute of Technology
AFOTEC	Air Force Operational Test and Evaluation Center
AFRL	Air Force Research Laboratory
AFSPC	Air Force Space Command
AFTA	Astrophysics Focused Telescope Assets
AGS	Atmospheric and Geospace Sciences
AIA	Atmospheric Imaging Assembly
AIR-Spec	airborne infrared spectrometer
APXS	Alpha Particle X-ray Spectrometer
ALMA	Atacama Large Millimeter/submillimeter Array
AMC	Additive Manufacturing Consortium
AMISR	Advanced Modular Incoherent-Scatter Radar
AMPERE	Active Magnetosphere and Planetary Electrodynamics Response Experiment
AMS	Autonomous Modular Sensor; Alpha Magnetic Spectrometer
ANWR	Arapaho National Wildlife Refuge
AO	Arecibo Observatory
APL	Applied Physics Laboratory
ARAIM	Advanced Receiver Autonomous Integrity Monitoring
ARM	Asteroid Redirect Mission; Atmospheric Radiation Measurement Climate Research Facility
ARMD	Aeronautics Research Mission Directorate
ARSET	Applied Remote Sensing Training
ARTCC	air route traffic control center
AS	Atmosphere Section
ASB	Agricultural Statistics Board
ASBU	Aviation System Block Upgrade
ASDE-X	Airport Surface Detection Equipment–Model X
ASR	Atmospheric System Research
ASRG	Advanced Stirling Radioisotope Generator
ASSC	Airport Surface Surveillance Capability System
AST	Office of Commercial Space Transportation; Division of Astronomical Sciences

ASTAR	Airborne Spacing for Terminal Arrival Routes
ASU	Group on the Sector Understanding on Export Credits for Civil Aircraft (also called Aircraft Sector Understanding)
ATST	Advanced Technology Solar Telescope
ATV	Automated Transfer Vehicle
AUVSI	Association for Unmanned Vehicle Systems International
AWiFS	Advanced Wide Field Sensor

B

BAA	Broad Agency Announcement
BANWR	Buenos Aires National Wildlife Refuge
BaPSF	Basic Plasma Science Facility
BEAM	Bigelow Expandable Activity Module
BIA	Bureau of Indian Affairs
BICEP	Background Imaging of Cosmic Extragalactic Polarization
BIS	Bureau of Industry and Security
BLM	Bureau of Land Management
BNL	Brookhaven National Laboratory
BOR	Bureau of Reclamation
BRICSat	Ballistic Reinforced Communication Satellite

C

C2V2	Common Communications for Visiting Vehicles
CA	cooperative agreement
CAL	Cold Atom Laboratory
CALET	CALorimetric Electron Telescope
CARVE	Carbon in Arctic Reservoirs Vulnerability Experiment
CAS	close air support
CATS	Cloud-Aerosol Transport System
CCAFS	Cape Canaveral Air Force Station
CCMC	Community Coordinated Modeling Center
CCS	Counter Communications System
CCSDS	Consultative Committee for Space Data Systems
CCtCap	Commercial Crew Transportation Capabilities
CD-3	Critical Decision–3
CDD	Capabilities Development Document
CDL	Cropland Data Layer
CDR	Critical Design Review
CEDAR	Coupling, Energetics, and Dynamics of Atmospheric Regions
CEPS	Center for Earth and Planetary Studies
CfA	Center for Astrophysics
CH_4	methane
CHAMP	CHAllenging Mini-satellite Payload
CIR	color infrared
CLU	Common Land Unit
CMB	cosmic microwave background
CNES	Centre Nationale d'Études Spatiales
C/NOFS	Communications/Navigation Outage Forecasting System
CO_2	carbon dioxide
COE CST	Center of Excellence for Commercial Space Transportation
COSMIC	Constellation Observing System for Meteorology, Ionosphere, and Climate
COSMO-SkyMed	COnstellation of small Satellites for the Mediterranean basin Observation
COSPAR	U.N. Committee on Space Research

COSPAS-SARSAT	Search and Rescue Satellite-Aided Tracking
CPGS	Conventional Prompt Global Strike
CPT	Command Post Terminal
CREAM	Cosmic Ray Energetics and Mass
CRP	Commercialization Readiness Program
CRSSP	Commercial Remote Sensing Space Policy
CS	Commercial Service
CSA	cooperative support agreement
CSLI	CubeSat Launch Initiative
CSP	Cold Spray Process
CubeSat	cube-shaped satellite
CYGNSS	Cyclone Global Navigation Satellite System

D

DAA	Detect-and-Avoid
DASC	Deep Space Atomic Clock
DASI	Degree Angular Scale Interferometer
Data Comm	Data Communications
DKAO	Dakotas Area Office
DKIST	Daniel K. Inouye Solar Telescope
DLR	German Aerospace Center
DMC	Disaster Monitoring Constellation
DNN	Defense Nuclear Nonproliferation
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DOS	Department of State
DPR	Dual-frequency Precipitation Radar
DRS	Disturbance Reduction System
DSCOVR	Deep Space Climate Observatory
DSN	Deep Space Network
DVE-M	Degraded Visual Environment Mitigation
DWH	Deepwater Horizon

E

EAWS	Early Access Web Services
EBIS	Electron Beam Ion Source
ECLIF	Emissions and Climate Impacts of Alternative Fuels
ECMWF	European Centre for Medium-Range Weather Forecasts
EDL	Entry, Descent, and Landing
EDSN	Edison Demonstration of SmallSat Networks
EELV	Evolved Expendable Launch Vehicle
EFSTS	Electronic Flight Strip Transfer System
EFT-1	Exploration Flight Test–1
EGS	Exploration Ground Systems
EIS	Environmental Impact Assessment
ELSO	Equivalent Lateral Spacing Operations
EM-1	Exploration Mission–1
EMC	Evolvable Mars Campaign
EOS	Earth Observing System
EPA	Environmental Protection Agency
EPS	Enhanced Polar System

ERAM	En Route Automation Modernization
ERAU	Embry-Riddle Aeronautical University
ERCDM	Eastern Range Command Destruct Modernization
EROS	Earth Resources Observation and Science; Earth Resources Observation Systems
ESA	European Space Agency
ESD	Earth Science Division
ESI	Exploration Systems Integration
ETM	Enhanced Thematic Mapper
EU	European Union
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EUV	extreme ultraviolet
eV	electronvolt
EVA	extravehicular activity
EVE	EUV Variability Experiment
EVI-3	Earth Venture Instrument–3
EVM-2	Earth Venture Mission–2
Ex-Im	Export-Import

F

FAA	Federal Aviation Administration
FAB-T	Family of Advanced Beyond Line of Sight Terminals
FACO	Final Assembly and Check Out
FAS	Foreign Agricultural Service
FAS/OGA	Foreign Agricultural Service Office of Global Analysis
FCC	Federal Communications Commission
FDSS	Faculty Development in Space Sciences
FES	Office of Fusion Energy Sciences
FGST	Fermi Gamma-ray Space Telescope
FIREBIRD	Focused Investigations of Relativistic Electron Burst Intensity, Range, and Dynamics
FOALS	Fuel Optimal and Accurate Landing System Test Flights
FOC	Full Operational Capability
FRAME	Fundamental Rotorcraft Acoustic Modeling for Experiments
FSA	Farm Service Agency
FTI	Federal Telecommunications Infrastructure
FWS	Fish and Wildlife Service

G

Gal/Xgal U/LDB	Galactic/Extragalactic Ultra-Long Duration Balloon
GaN	gallium nitride
GAO	Government Accountability Office
GBD	Global Burst Detector
GBSD	Ground Based Strategic Deterrent
GBU	Guided Bomb Unit
GCD	Game Changing Development
GEARRSAT	Globalstar Experiment And Risk Reduction Satellite Flight Experiment
GEDI	Global Ecosystem Dynamics Investigation
GEM	Geospace Environment Modeling
GEO	Geosynchronous Earth Orbit; Directorate for Geosciences
GEODSS	Ground-based Electro Optical Deep Space Surveillance
GF	Geospace Facilities
GIS	Geographic Information Systems
GLAM	Global Agricultural Monitoring

GLBA	Glacier Bay National Park and Preserve
GLOBE	Global Learning and Observations to Benefit the Environment
GMI	GPM Microwave Imager
GNSS	Global Navigation Satellite System
GOES	Geostationary Operational Environmental Satellite
GOES-R	Geostationary Operational Environmental Satellite–R
GOLD	Global-scale Observations of the Limb and Disk
GONG	Global Oscillations Network Group
GPHS	General Purpose Heat Source
GPIM	Green Propellant Infusion Mission
GPM	Global Precipitation Measurement
GPR	ground penetrating radar
GPS	Global Positioning System
GPS/MET	GPS/Meteorology
GPSRO	GPS radio occultation
GRACE	Gravity Recovery and Climate Experiment
GRACE-FO	Gravity Recovery and Climate Experiment Follow-On
GRC	Glenn Research Center
G-REALM	Global Reservoir and Lake Monitor
GS	Geospace Section
GSDO	Ground Systems Development and Operations
GSFC	Goddard Space Flight Center
GT-1	Ground Tournament
GUSTO	Gal/Xgal U/LDB Spectroscopic–Stratospheric Terahertz Observatory

H

HCT	Hall Current Thruster
HEAT	High Elevation Antarctic Terahertz
HEEET	Heatshield for Extreme Entry Environment Technology
HEO	Highly Elliptical Orbit
HEOMD	Human Exploration and Operations Mission Directorate
HEP	Office of High Energy Physics
HiRISE	High Resolution Imaging Science Experiment
HIWC	High Ice Water Content
HOPE	Hands-On Project Experience
HPD	Heliophysics Division
HRP	Human Research Program
HRS	Human Robotic Systems
HTV	H-II Transfer Vehicle
HX	Heat Exchanger

I

I&M	Inventory and Monitoring
ICAO	International Civil Aviation Organization
ICBM	intercontinental ballistic missile
ICE-Cap	Integrated Communications Extension Capability
ICG	International Committee on GNSS
ICNO	IceCube Neutrino Observatory
ICON	Ionospheric Connection Explorer
IDEX	International Defense Exhibition and Conference
IDIQ2	indefinite-delivery, indefinite-quantity
IFAR	International Forum for Aviation Research

IfSAR	Interferometric Synthetic Aperture Radar
InSight	Interior Exploration Using Seismic Investigations, Geodesy and Heat Transport
IOC	Initial Operational Capability
ION	Institute of Navigation
IPAD	International Production Assessment Division
IPCC	Internet Protocol Companion Contract
IRAC	Infrared Array Camera
IRIS	Interface Region Imaging Spectrograph
ISECG	International Space Exploration Coordination Group
ISEF2	International Space Exploration Forum
ISRO	Indian Space Research Organisation
ISS	International Space Station
ISS-RapidScat	International Space Station–Rapid Scatterometer
IST	Integrated Systems Test
ITA	International Trade Administration
ITU	International Telecommunication Union
IXPE	Imaging X-ray Polarimetry Explorer

J

JASD	Joint Agency Satellite Division
Jason	Joint Altimetry Satellite Oceanography Network
JAXA	Japan Aerospace Exploration Agency
JCTD	Joint Capability Technology Demonstration
JMR	Joint Multi-Role
JMS	JSpOC Mission System
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System
JSC	Johnson Space Center
JSF	Joint Strike Fighter
JSpOC	Joint Space Operations Center
JUICE	Jupiter Icy Moons Explorer
JWST	James Webb Space Telescope

K

KDP	Key Decision Point
KSC	Kennedy Space Center
KUS	Kennedy Uplink Station

L

LAAD	Latin America Aerospace and Defence
LANL	Los Alamos National Laboratory
LAPD	Large Plasma Device
LAT	Large Area Telescope
LCH_4	liquid methane
LCMS	Landscape Change Monitoring System
LCRD	Laser Communication Relay Demonstration
LCS	Launch Communications System
LDSD	Low Density Supersonic Decelerator
lidar	light identification detection and ranging
LISA	Laser Interferometer Space Antenna
LLNL	Lawrence Livermore National Laboratory

LORRI	Long Range Reconnaissance Imager
LOX	liquid oxygen
LRO	Lunar Reconnaissance Orbiter
LSC	Legal Subcommittee
LSP	Launch Services Program
LSST	Large Synoptic Survey Telescope
LST	Land Surface Temperature
LTS	Working Group on Long-Term Sustainability of Outer Space Activities
Lunar CATALYST	Lunar Cargo Transportation and Landing by Soft Touchdown

M

M&S	modeling and simulation
MAIAC	Multi-Angle Implementation of Atmospheric Correction
MARS	Mid-Atlantic Regional Spaceport
MARSIS	Mars Advanced Radar for Subsurface and Ionosphere Sounding
MARSOC	Marine Special Operations Command
MAVEN	Mars Atmosphere and Volatile Evolution
MDA	Missile Defense Agency
MEDA	Mars Environmental Dynamics Analyzer
MEDLI	Mars Entry, Descent, and Landing Instrumentation
MEN	Modernization Eastern Range Network
MEP	Manufacturing Extension Partnership
MER	Mars Exploration Rover
MESSENGER	MErcury Surface, Space ENvironment, GEochemistry, and Ranging
MetOp	Meteorological Operational Satellite Program
METOP-A/GRAS	Meteorological Operational satellite programme–A/Global navigation satellite system Receiver for Atmospheric Sounding
MEU	Marine Expeditionary Units
MIT	Massachusetts Institute of Technology
MMRTG	Multi-Mission Radioisotope Thermoelectric Generator
MMS	Magnetospheric Multiscale
MOA	Memorandum of Agreement
MOBY	Marine Optical Buoy
MODIS	Moderate Resolution Imaging Spectroradiometer
MOPS	Minimum Operational Performance Standards
MOT&E	Multi-Service Operational Test and Evaluation
MOU	Memorandum of Understanding
MOXIE	Mars Oxygen In Situ Resource Utilization Experiment
MPE	Mission Planning Element
MPS	Mathematics and Physical Sciences
MRLC	Multi-Resolution Land Characteristics Consortium
MRO	Mars Reconnaissance Orbiter
MRP	Mineral Resources Program
MRX	Magnetic Reconnection Experiment
MSFC	Marshall Space Flight Center
MSIP	Mid-Scale Innovations Program
MSL	Mars Science Laboratory
MTBS	Monitoring Trends in Burn Severity
MUOS	Mobile User Objective System

N

NAICS	North American Industry Classification System

NAIP	National Agriculture Imagery Program
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASM	National Air and Space Museum
NASS	National Agricultural Statistics Service
NATCA	National Air Traffic Controllers Association
NBR	normalized burned area ratio
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NDVI	Normalized Difference Vegetation Index
NE	Office of Nuclear Energy
NEA	Near-Earth Asteroid
NEN	Near Earth Network
NEO	near-Earth object
NERSC	National Energy Research Supercomputing Center
NextGen	Next Generation Air Transportation System
NextSTEP	Next Space Technology Exploration Partnerships
NFS	National Forest System
NGEE	Next Generation Ecosystem Experiment
NGO	nongovernmental organization
NHD	National Hydrography Dataset
NIAC	NASA Innovative Advanced Concepts
NICER	Neutron star Composition and Interior Explorer
NIR	near-infrared
NISAR	NASA–ISRO Synthetic Aperture Radar
NIST	National Institute of Standards and Technology
NISTAR	NIST Advanced Radiometer
NLCD	National Land Cover Database
NMAMLP	New Mexico Abandoned Mine Land Program
NNSA	National Nuclear Security Administration
NOAA	National Oceanic and Atmospheric Administration
NOAO	National Optical Astronomy Observatory
NOC	National Operations Center
NPOESS	National Polar-Orbiting Operational Environmental Satellite System
NPS	National Park Service
NRAO	National Radio Astronomy Observatory
NRCS	Natural Resources Conservation Service
NRA	NASA Research Announcement
NRL	Naval Research Laboratory
NSF	National Science Foundation
NSO	National Solar Observatory
NSPO	National Space Organization
NSRL	NASA Space Radiation Laboratory
NSS	national security space
NSTC	National Science and Technology Council
NSWS	National Space Weather Strategy
NTC	National Training Center
NTP	Nuclear Thermal Propulsion
NuDets	space nuclear detonations
NWP	numerical weather prediction

O

OCO-2	Orbiting Carbon Observatory 2
ODNI	Office of the Director of National Intelligence

OECD	Organization for Economic Cooperation and Development
OFII	Office of Finance and Insurance Industries
OIB	Operation IceBridge
OIG	Office of Inspector General
OLI	Operational Land Imager
OMB	Office of Management and Budget
OPIR	Overhead Persistent Infrared
ORS	Operationally Responsive Space
OSD	Office of the Secretary of Defense
OSMRE	Office of Surface Mining Reclamation and Enforcement
OSP-3	Orbital/Suborbital Program–3
OSTP	Office of Science and Technology Policy
OTM	Office of Transportation and Machinery
OTV	Orbital Test Vehicle
OVERFLOW	OVERset grid FLOW solver

P

PACE	Pre-Aerosol, Clouds, and ocean Ecosystem
PBN	Performance Based Navigation
PBS	Plum Brook Station
PCAS	Persistent Close Air Support
PCM	Phase Change Material
PCM HX	Phase Change Material Heat Exchanger
PDL	Ponce De Leon
PDR	Preliminary Design Review
PECAN	Plains Elevated Convection at Night
PLR	Division of Polar Programs
PNT	Positioning, Navigation, and Timing
POES	Polar-orbiting Operational Environmental Satellites
POLARBEAR	Polarization of Background Radiation
PolSAR	Polarimetric synthetic aperture radar
PPPL	Princeton Plasma Physics Laboratory
PRAXyS	Polarimeter for Relativistic Astrophysical X-ray Sources
PRS	Public Regulated Service
Psat	Parkinson Satellite
PSD	Planetary Science Division; production, supply, and distribution
Pu	plutonium

Q

QZSS	Quasi-Zenith Satellite System

R

R&D	Research and Development
RapidScat	Rapid Scatterometer
REDDI-2014	Research, Development, Demonstration, and Infusion 2014
RERP	Reliability Enhancement and Re-engining Program
RHIC	Relativistic Heavy Ion Collider
RHU	radioisotope heater unit
RNAV	Area Navigation
RNP	Required Navigation Performance
RO	radio occultation
ROD	Record of Decision

ROSES	Research Opportunities in Space and Earth Sciences
Rp	refined petroleum
RP-1	liquid kerosene
RPS	radioisotope power system
RPT	Rocket Propulsion Test
RRM-P2	Robotic Refueling Mission Phase 2
RSAC	Remote Sensing Applications Center
RSCC	Remote Sensing Coordinating Committee
RSIWG	Remote Sensing Interagency Working Group
RTCA-SC228	Radio Technical Commission for Aeronautics–Special Committee 228
RTG	Radioisotope Thermoelectric Generator
RTK-GPS	Real-Time Kinematic Global Positioning System
RV	recreational vehicle

S

S&CD	Strategic and Commerce Dialogue
SABRS	Space and Atmospheric Burst Reporting System
SAC-C	Satélite de Aplicaciones Científic
SAM	Sample Analysis at Mars
SAME	Smoke Aerosol Measurement Experiment
SAO	Smithsonian Astrophysical Observatory
SAR	Synthetic Aperture Radar
SATCOM	Satellite Communications
SBIR	Small Business Innovation Research
SBIRS	Space Based Infrared System
SBSS	Space Based Space Surveillance Follow-On
SC	Office of Science
SCaN	Space Communications and Navigation
S-CANDELS	Spitzer-Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey
SDB	Small Diameter Bomb
SDO	Solar Dynamics Observatory
SEP	Solar Electric Propulsion
SfM	Structure from Motion
SGSS	Space Network Ground Segment Sustainment
SHARAD	Shallow Subsurface Radar
SHINE	Solar, Heliosphere, and INterplanetary Environment
SIA	Satellite Imagery Archive
SIAD	Supersonic Inflatable Aerodynamic Decelerator
SIR	Systems Integration Review
SLAC	Stanford Linear Accelerator Center
SLEP	Service Life Extension Program
SLS	Space Launch System
SM	Service Module
SM-6	Standard Missile–6
SMAP	Soil Moisture Active Passive
SMC	Space and Missile Systems Center
SMCRA	Surface Mining Control and Reclamation Act
SMD	Science Mission Directorate
SN	Space Network
SNL	Sandia National Laboratories
SNSPD	superconducting nanowire single-photon detector
SOC	Space Optical Clock
SOFEX	Special Operations Forces Exhibition and Conference
SOFIA	Stratospheric Observatory for Infrared Astronomy

SP-9	Service Pack 9
SpaceX	Space Exploration Technologies Corporation
SPAWAR	Space and Naval Warfare Systems Command
SPB	super-pressure balloon
SPD	supersonic particle deposition
SPHEREx	Spectrophotometer for the History of the Universe, Epoch of Reionization, and Ices Explorer
SPP	Solar Probe Plus
SPT	South Pole Telescope
SPTpol	SPT polarization-sensitive
SPUD	Small Polarimeter Upgrade for DASI
SQUID	Superconducting Quantum Interference Devices
sRLV	suborbital reusable launch vehicle
SSA	Space Situational Awareness
SSC	Stennis Space Center
SSDP	Space Security and Defense Program
SST	Space Surveillance Telescope
SSTI	Small Spacecraft Technology Initiative
SSTP	Small Spacecraft Technology Program
StareWAI	Staring Wide Area Imager
STB	SCaN Testbed
STDDS	SWIM Terminal Data Distribution System
STE	Special Test Equipment
STEM	science, technology, engineering, and mathematics
STIM	Space Transportation Infrastructure Matching
STMD	Space Technology Mission Directorate
STP	Space Test Program
STSC	Scientific and Technical Subcommittee
STTR	Small Technology Transfer Research
Suomi NPP	Suomi National Polar-orbiting Partnership
SURF	Synchrotron Ultraviolet Radiation Facility
SVT	Surface Visualization Tool
SWIM	System Wide Information Management
SWORM	Space Weather Operations, Research, and Mitigation
SWPC	Space Weather Prediction Center
SWR	Space Weather Research
SwRI	Southwest Research Institute
SXS	Soft X-ray Spectrometer
SZ	Sunyaev-Zel'dovich

T

TAP	Traffic Aware Planner
TCAS	Traffic alert and Collision Avoidance System
TCC	Tree Canopy Cover
TCCON	Total Column Carbon Observing Network
TD	Technology Demonstrator
TDRSS	Tracking and Data Relay Satellite System
TES	transition-edge sensor; Terrestrial Ecosystem Science
TESNAR	TEchnical training in Support of Native American Relations
TESS	Transiting Exoplanet Survey Satellite
TeV	teraelectronvolt
TFDM	Terminal Flight Data Manager
TFMS	Traffic Flow Management System
TIN	triangulated irregular network
TM	Thematic Mapper

TMAS	Thermal Mapping Airborne Simulator
TMRR	Technology Maturation and Risk Reduction
TOPEX	Ocean Topography Experiment
TPS	Thermal Protection Systems
TRACON	Terminal Radar Approach Controls
TRL	Technology Readiness Level
TRMM	Tropical Rainfall Measuring Mission
TSAS	Terminal Sequencing and Spacing
TWG	Technical Working Group

U

UAF	University of Alaska Fairbanks
UAS	Unmanned Aircraft Systems
UAVSAR	Uninhabited Aerial Vehicle Synthetic Aperture Radar
UCAR	University Corporation for Atmospheric Research
UCC	Unified Combatant Commander
UHF	Ultra-High Frequency
ULA	United Launch Alliance
USAF	United States Air Force
USDA	U.S. Department of Agriculture
USFS	United States Forest Service
USGS	United States Geological Survey
USIP	Undergraduate Student Instrument Project
USNDS	U.S. NuDet Detection System
UTM	UAS Traffic Management

V

VAC	Vertical Assembly Center
VAFB	Vandenberg Air Force Base
VCLS	Venture Class Launch Service
VIIRS	Visible Infrared Imaging Radiometer Suite
VIPR	Vehicle Integrated Propulsion Research
VTOL	Vertical Take-Off and Landing

W

WASDE	World Agricultural Supply and Demand Estimates
WCDMA	Wideband Code Division Multiple Access
WFIRST	Wide-Field Infrared Survey Telescope
WGS	Wideband Global SATCOM
WGSC	Western Geographic Science Center
WRCDM	Western Range Command Destruct Modernization
WSGF	Weather System Gap Filler
WSTF	White Sands Test Facility

X

XRT	X-Ray Telescope

Y

Yb	ytterbium

NP-2016-03-2136-HQ