"Jules Verne" Automated Transfer Vehicle (ATV) Re-entry

Information Kit

Updated: September 2008

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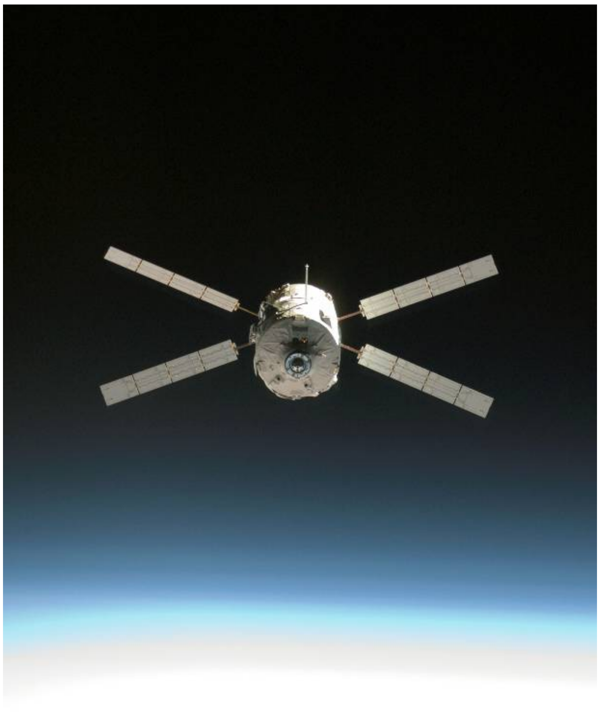
The Mission So Far

The first European Automated Transfer Vehicle (ATV), 'Jules Verne', was launched to the ISS from the European Spaceport in French Guiana by an Ariane 5 launcher on 9 March 2008. It will reach the end of its six- month mission after undocking on 5 September 2008, with a planned destructive deorbit into Earth's atmosphere on 29 September. The ATV is one of the indispensable ISS supply spacecraft and transported 6 tonnes of cargo to the ISS. This included ISS reboost and refuelling propellants, water, oxygen, and 1.3 tonnes of dry cargo including food, clothing, spare parts and additional items. In keeping with the name of the first ATV mission, an original 19th century luxury edition of Jules Verne's book 'De la Terre à la Lune' and two of his handwritten manuscripts were also transported to the ISS in the ATV.

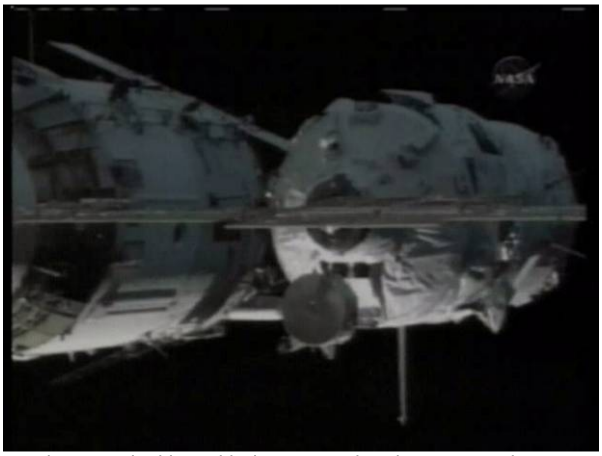
ISS Expedition 17 crew inside the ATV after retrieving the 19th century luxury edition of Jules Verne's book 'De la Terre à la Lune' and handwritten manuscripts. From left: NASA astronaut Greg Chamitoff and Russian cosmonauts Oleg Kononenko and Sergei Volkov. (Image: NASA)

Launch of the 'Jules Verne' Automated Transfer Vehicle (ATV) to the ISS by an Ariane 5 launcher on 9 March 2008.
(Image: ESA /CNES/Arianespace/Photo optique video du CSG)

Following its launch, the ATV was put through a series of manoeuvres across two demonstration days to ensure that it could safely undertake rendezvous and docking procedures and collision avoidance manoeuvres with the ISS if necessary. With these manoeuvres and the actual rendezvous and docking with the ISS going perfectly on 3 April 2008, Jules Verne saved over 870 kg of propulsion fuel. This gave it the possibility to perform additional Station reboosts before undocking,



The 'Jules Verne' ATV during Demonstration day 2 on 31 March 2008. (Image: NASA)



The ATV docking with the International Space Station on 3 April 2008. (Image: ESA TV)

thus extending the ATV's mission in orbit from August to September. Reboosts are used to place the ISS in a higher orbiting altitude to counter the affects of atmospheric drag. Whilst attached to the ISS as a pressurised module the ATV has reboosted the Station four times, been used to control the ISS attitude, and also carried out a debris avoidance manoeuvre on 27 August, the first time that such a manoeuvre has occurred since 2003.

Artist's impression of the ATV reboosting the International Space Station to a higher orbiting altitude. (Image: ESA/D. Ducros)

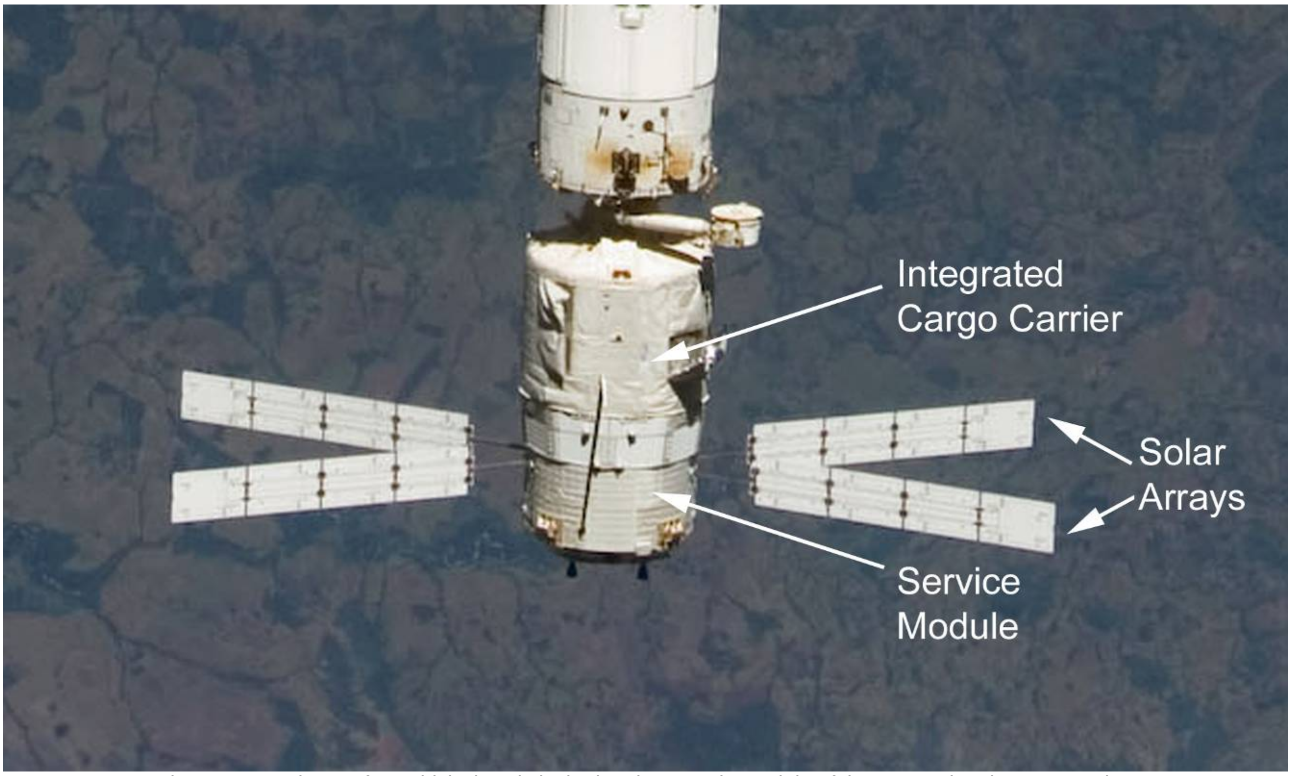
On 17 June, two days prior to the second reboost, the ATV was used to transfer 810 kg of refuelling propellant to the International Space Station. This made it the first western spaceship to succeed in refuelling another piece of space infrastructure in orbit. This fluid transfer included 280 kg of unsymmetrical dimethylhydrazine propellant fuel and 530 kg of nitrogen tetroxide, (which provides a source of oxygen so the fuel can ignite and burn in orbit).

In addition to the previous tasks, the ATV has derived a number of new uses while in orbit, not within the original mission plans: crewmembers have used the spacecraft as a new area to sleep as the sound level of the ventilator fans and air circulation is relatively low; instead of using the usual Crew Hygiene Station, the crew have taken advantage of the large space inside the ATV to keep themselves clean using their usual wet fabric towels, treated napkins and alcohol-free rinseless shampoo; one of the ATV's empty tanks was used to store 110 litres of un-recycled condensation water from the ISS, which is currently stored in five 22 litre water bags inside the ATV; and the ATV has also been used to perform experiments by the first South Korean female astronaut, Yi So-yeon, during her 11-day space journey in April.

The ATV during fuelling operations prior to launch.
(Image: ESA /CNES/Arianespace/Photo optique video du CSG)

Before undocking, liquid waste from the Station's toilet was transferred to the ATV's tanks via valves and flexible hosepipes or foldable plastic containers. The crew also gradually filled the cargo section with the waste and equipment that is no longer used on the ISS. After undocking, the Jules Verne ATV will burn up in a controlled re-entry into Earth's atmosphere over a completely uninhabited area of the Pacific Ocean, in the process eliminating 2½ tonnes of waste material inside.

ATV Overview



The Automated Transfer Vehicle (ATV) docked to the Zvezda Module of the International Space Station.
Photo taken from STS-124 Discovery on 11 June 2008 following undocking. (Image: NASA)

New generation spaceship
Approximately every 18 months or so, an ATV will be launched into orbit to deliver up to 7½ tonnes of cargo to the International Space Station. It will use its high-precision navigation systems to automatically rendezvous and dock with the Station's Russian Service Module, Zvezda.

The ATV, which is equipped with its own propulsion and navigation systems, is a multi–functional spaceship, which combines both the fully automatic capabilities of an unmanned vehicle with human spacecraft safety requirements. It was developed by the European Space Agency and European Industry as a highly sophisticated, new generation spacecraft capable of docking safely with the ISS.

The exterior is a cylinder, 10.3 metres long and up to 4.5 metres in diameter covered with a thermally insulating foil layer on top of meteorite protection panels. Extending from the main body of the spacecraft are its characteristic X-shaped metallic blue solar arrays.

Inside, the ATV consists of two modules: the ATV Service Module containing the navigation and propulsion systems; and the pressurised Integrated Cargo Carrier, which housed the fluid and dry cargo transported to the ISS. The forward part of this Cargo Carrier docked with the ISS.

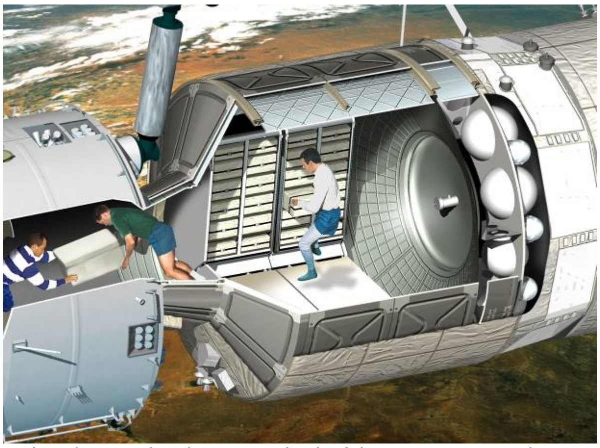
Although no one will ever be launched in an ATV, astronauts dressed in regular clothing can enter its pressurised section from inside the ISS for loading and unloading cargo and equipment and other relevant tasks.

The combination of the ATV and the Ariane 5 provides Europe with the independent capability to transport European equipment to the Station. This has very important political and operational implications. By transporting propellants, gases and other logistics goods to the Station for the common use by the ISS partners and ISS systems, Europe is contributing towards its share of the Space Station operating costs. At the same time it enables the delivery of experiments and scientific facilities for use in the European Columbus laboratory, which was launched and attached to the ISS in February 2008. The ATV is developed under ESA contract by a European industrial consortium lead by EADS Astrium.

The Integrated Cargo Carrier

Expedition 17 crewmembers, Sergei Volkov and Oleg Kononenko, working with stowage bags inside the ATV on 12 May 2008. (Image: NASA)

The Integrated Cargo Carrier is located on the forward end of the ATV, i.e. the end that is docked with the ISS. It represents 60% of the total ATV volume and carried all of the cargo for resupplying the Station.



Artist's impression (cutaway view) of the ATV Integrated Cargo Carrier attached to the ISS. (Image: ESA/D. Ducros)

Pressurised Section (Dry cargo)

After docking with the Station and carrying out important procedures such as leak checks, the crew opened the Zvezda hatch, retracted the ATV docking mechanism and entered the 48 m³ pressurised section of the Integrated Cargo Carrier. Shortly after entering the ATV the crew set up and activated an air filtering device that was left to run for 8 hours to remove any unwanted gasses or small particles of debris that may have been floating around.

Up to two astronauts can work in Jules Verne, unloading supplies and conducting experiments, while the hatch remains constantly open between the ISS and the ATV. The pressurised section contained the dry cargo such as maintenance supplies, science hardware, and parcels of fresh food, mail and personal items. It accounts for 90% of the volume of the Integrated Cargo Carrier. The pressurised section has room for up to eight standard racks which are designed with modular aluminium elements to store equipment and transfer bags.

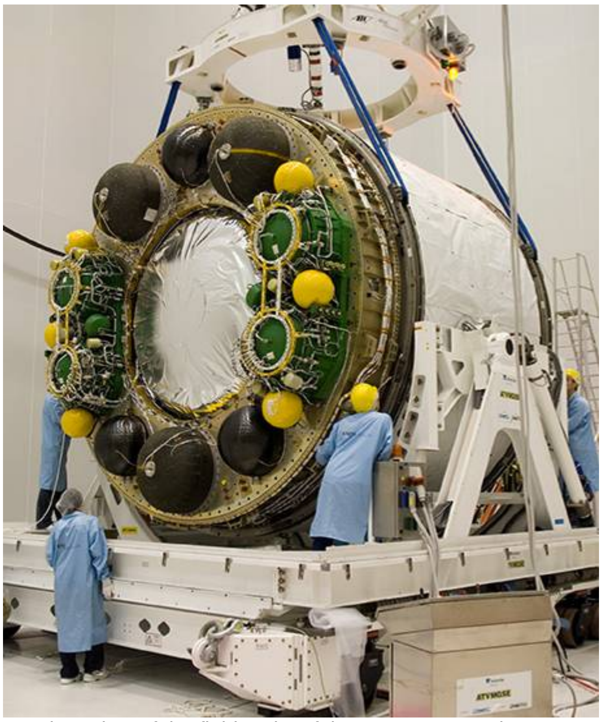
Russian cosmonaut Yuri Malenchenko and NASA astronaut Peggy Whitson setting up air filtration device in the ATV on 4 April 2008 (Image: ESA TV)

The ATV pressurised cargo section is based on the Italian-built Multi-Purpose Logistics Module (MPLM), which is already in service as a Shuttle-carried 'space barge' transporting equipment to and from the Station.

Multi-Purpose Logistics Module (MPLM) in Shuttle cargo bay during docking of STS-121 Discovery mission on 6 July 2006. The flight also brought ESA astronaut Thomas Reiter to the ISS to serve as the first European ISS Expedition crew member. The ATV Integrated Cargo Carrier is based on the MPLM. (Image: NASA)

Unpressurised section (Fluid cargo)

Behind the back wall or interface of the pressurised section is the unpressurised section of the Integrated Cargo Carrier where fluid cargo is stored. This external bay houses 22 spherical fluid tanks of different sizes and colours. These tanks have resupplied the Station with refuelling propellant for the Station's own propulsion system, and water and air (oxygen and nitrogen) for the crew. This cylindrical bay and its tanks are not visible from outside the ATV as they are enclosed by the ATV Service Module. The fluid tanks' contents are transferred through either dedicated pipes to the Station's own fluid lines or through manually operated hoses.



Clear view of the fluid tanks of the ATV Integrated Cargo Carrier during procedures to tilt it to an upright position prior to mating it with the ATV Service Module on 14 December 2007. (Image: ESA /CNES/Arianespace/Photo optique video du CSG)

Cargo Capabilities

The ATV is designed to resupply the ISS with up to 7.5 tonnes of cargo. Depending on the needs of the ISS, the ATV is able to accommodate very different combinations of supplies, carrying up to:

- 840 kg of drinking water;
- 100 kg of air (oxygen and nitrogen);
- 860 kg of refuelling propellant for the Station's propulsion system;
- 4700 kg of propellant for reboost;
- 5500 kg of dry supplies like bags, drawers and fresh food;

Russian cosmonaut Yuri Malenchenko removing the ATV docking mechanism in order to enter the ATV Integrated Cargo Carrier for the first time on orbit on 4 April 2008. (Image: ESA TV)

Front Cone (Rendezvous/Docking Equipment)
The 'nose' of the Integrated Cargo Carrier houses the Russian-made docking system and avionics and propulsion hardware, which was critical to the automatic approach, rendezvous and docking of the ATV with the ISS. There are two videometers (image processing system able to compute distance and orientation of the ISS), two telegoniometers, (which continuously calculated distance and direction from the ATV to the ISS), two star trackers (able to recognize constellations in the sky), two visual video targets (used by the ISS crew for visual monitoring of the ATV during final approach) and 8 minijets for attitude control.

ATV docking mechanism during Demonstration Day 2 in orbit, when it was brought to within 11 metres of the ISS on 31 March 2008. (Image: NASA)

The ATV was the active spacecraft during rendezvous with the ISS. The 235 kg Russian docking system of the ATV docked to the back of the Zvezda module (this docking port can also be used for docking Progress supply craft and Soyuz spacecraft). The ATV docking mechanism enabled physical, electrical and propellant connections with the Station. It also allowed the ISS crew to access the pressurised section of the Integrated Cargo Carrier through its 80 cm-diameter hatch by retracting the docking mechanism. The Russian docking system has been continuously refined since it was originally developed in the late 1960s for the Salyut space station programme, and it remains the worldwide state of the art in docking mechanisms.

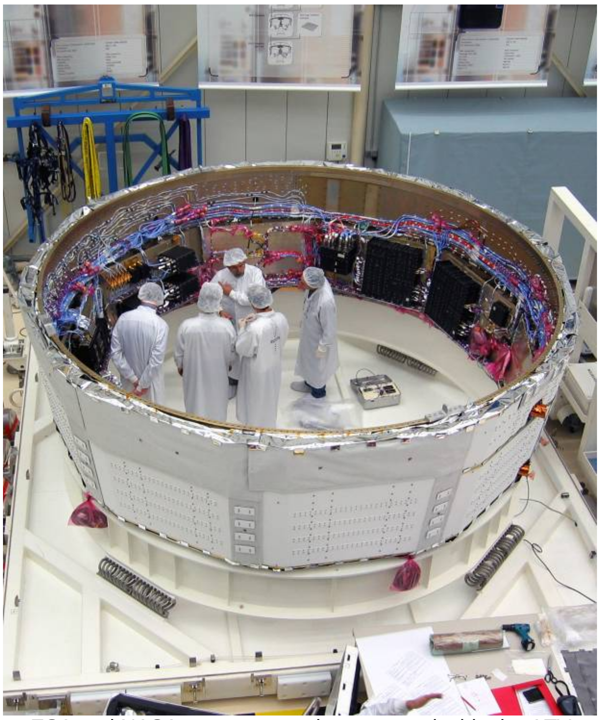
The ATV Service Module

The ATV Service Module being hoisted into position for mating with the Integrated Cargo Carrier on 12 December 2007. Two solar panels shown folded up. (Image: ESA /CNES/Arianespace/Photo optique video du CSG)

The unpressurised ATV Service Module includes propulsion systems, electrical power (including solar arrays), computers, communications and most of the avionics. With its own flight-control and propulsion systems, the ATV has a high level of autonomy which allows it to stay in free flight for long periods of time, as well as allowing it to dock even if the Station is totally dormant and unmanned. After docking, these systems have been used to perform necessary ISS tasks including attitude control and raising the Station to a higher orbital altitude to overcome the effects of atmospheric drag. These systems will be used following undocking to de-orbit the spacecraft in order to perform a controlled destructive re-entry into Earth's atmosphere high above the Pacific Ocean.

Avionics

The avionics bay is the brain of the ATV. It looks like a cylindrical ring of 1.36 m high, and is located in the upper part of the Service Module. It accommodates critical items like computers, gyroscopes, navigation and control systems and communications equipment. All these items are mounted on ten equipment carrier trays which are protected from the temperature variations by state-of-the-art heat pipes. The ATV Service Module takes advantage of a very sophisticated architecture for its hardware and software in order to keep the ATV functioning in case of hardware failure or main malfunction.



ESA and NASA managers and astronauts inside the ATV Avionics Bay on 19 November 2003 prior to mating with the propulsion bay of the ATV Service Module. (Image: ESA)

Electrical Power

The Service Module houses the four solar arrays, which were deployed 100 minutes after lift-off. These have a total span of 22.3 m and provide electrical power to rechargeable batteries, which are vital for powering ATV systems during eclipse periods in orbit. The solar arrays are comprised of silicium solar cells, spread on 4 carbon fibre reinforced plastic sandwich panels per array with a total surface area of 33.6 m² (4 x 8.4 m²) and able to produce an average of 4800 watts. Mounted on the ATV Service Module, the four

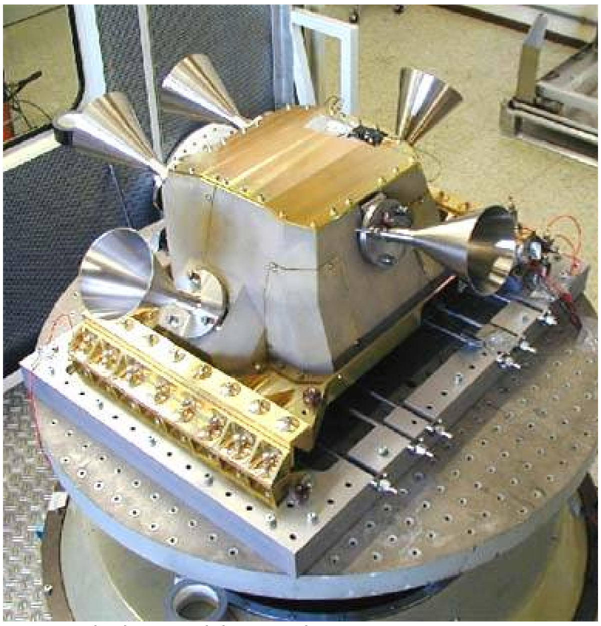
Rear view of ATV docked to the ISS on with clear view of cross-shaped solar arrays. (Image: NASA)

Sun tracking arrays are totally independent and can get the best orientation to the Sun thanks to rotating mechanisms.

End of the ATV propulsion bay clearly showing four main thrusters and one complete attitude control thruster cluster (lower right) covered with red protective caps. Photo taken on 13 December 2007.
(Image: ESA /CNES/Arianespace/Photo optique video du CSG)

Propulsion

The ATV propulsion system provided the spaceship with the capability to transport the ATV to the ISS, navigating as a fully automatic spaceship with four main engines (providing 490 N thrust) plus 28 smaller thrusters (providing 220 N) for attitude control. All valves and thrusters are controlled by four control units connected to the main ATV computers. When docked to the Station, the ATV's propulsion capabilities were used for ISS attitude control, a debris avoidance manoeuvre and reboosting the Station. In order to perform the task of reboost the ATV may use up to 4.7 tonnes of its own propellant at intermittent intervals. At the end of the mission the ATV Service Module thrusters will use their remaining fuel to de-orbit the spacecraft.



Attitude control thruster cluster. (Image: EADS Astrium)

All the propellant tanks for spaceship propulsion are located in the ATV Service Module, between the main engines and the avionics bay. There are eight titanium propellant tanks and two high pressure carbon-fibre helium tanks. The propellant tanks hold up to seven tonnes of monomethylhydrazine (MMH) and nitrogen tetroxide (N_2O_4), part of which is used for the station attitude and orbit control. These propellants are pressurised by the helium.

Key Mission Data

MISSION	
Mission Name:	'Jules Verne' ATV Mission
ISS Mission Designation	ATV1
SPACECRAFT	
Spacecraft	Automated Transfer Vehicle (ATV)
Spacecraft mass at undocking	~ 13470 kg
Launch/Docking parameters	
Launch Date	9 March 2008
Launch Site	European Spaceport, Kourou, French Guiana
Launcher	Ariane 5 ES ATV
Docking Date	3 April 2008
UNDOCKING/REENTRY PARAMETERS	
Undocking Date/Time	5 September 2008 (21:32 GMT, 23:32CEST)
Undocking altitude	~360 km
Inclination	51.6°
Departure Burn	5 September 2008 (21:33 GMT, 23:33 CEST)
Burn Duration, Impulse	4 min 52 s, -4 m/s
First Orbit Transfer Burn	15 September 2008 (11:38 GMT, 13:38 CEST)
Burn Duration, Impulse	1 min 49 s, 8.21 m/s
Second Orbit Transfer Burn	15 September 2008 (12:33 GMT, 14:33 CEST)
Burn Duration, Impulse	1 min 50 s, 8.21 m/s
Altitude at Burn End	~318 km
First Mid-Course Manoeuvres	19 September 2008
Second Mid-Course Manoeuvres	24 September 2008
Orbital Alignment Manoeuvres	27 September 2008
Burn Duration, Impulse	1 x 3 min 42 s, 2.49 m/s x 3 min 48 s, 2.56 m/s
Transfer to Interface Point Manoeuvres	28 September 2008
Burn Duration, Impulse	2 x 2 min 31 s, 1.7 m/s
Altitude at Burn End	~324 km
Deorbit Burn 1	29 September 2008 (10:11 GMT, 12:11 CEST)
Burn Duration, Impulse	6 min 1 s, -29.7 m/s
Altitude at Burn End	220 km – 330 km
Deorbit Burn 2	29 September 2008 (13:09 GMT, 15:09 CEST)
Burn Duration, Impulse	13 min 56 s, -69.8 m/s
Re-entry (at 120km altitude)	13:42 GMT, 15:42 CEST
Impact of residual fragments	13:54 GMT, 15:54 CEST
ISS CREW AT UNDOCKING (Expedition 17)	Sergei Volkov, Commander (Roscosmos) Oleg Kononenko, Flight Engineer 1 (Roscosmos) Greg Chamitoff, Flight Engineer 2 (NASA)

(Please note that times can vary by +/- 45 mins from the given timeline and can also change due to a change in the nominal mission plan)

Final ATV Preparation and Hatch Closure

Preparations for the undocking of the ATV will actually start more than two days prior to undocking with cargo and equipment still required on the ISS being removed from the ATV and the crew loading the ATV with any old equipment or waste no longer needed on the Station.

ISS Commander Sergei Volkov (left) and Flight Engineer Oleg Kononenko by cargo racks in the ATV Integrated Cargo Carrier. (Image: NASA)

The Proximity Communication Equipment used for communication between the Station and the ATV for undocking is removed from its stowage container, installed in the Zvezda Service Module of the ISS, reactivated and, over two sequential days, checked out to make sure it is working properly. After being used during rendezvous operations, the two-way Proximity Communication Equipment, had been deactivated while the ATV was attached to the ISS.

Various systems are checked and reconfigured in the last two days before undocking. This includes: checking the links with the European Artemis and US TDRS satellites, which will be utilised during the undocking and re-entry procedures for communication between the ATV and the ATV Control Centre: reactivating the ATV's Guidance, Navigation and Control; and initialising the Monitoring and Safing Unit. The Monitoring and Safing Unit is a backup computer, which isolates the ATV's primary systems upon detection of a double failure or an unsafe situation, and can command the ATV to carry out a Collision Avoidance Manoeuvre.

NASA astronaut and Expedition 16 Flight Engineer Garrett Reisman entering the ATV past the ATV docking mechanism and inter-module air hose (Image: ESA TV)

Prior to hatch closure the crew remove safety equipment (fire extinguisher and breathing apparatus), an inter-module air hose, and various hand grips and restraints from inside the ATV. They turn on a valve that stabilises ATV pressure after hatch closure, and turn off the ATV fan and smoke detectors.

One day before leaving, the ATV hatch is closed and 16 quick release clamps are removed from around the periphery of the interhatch area between the ATV and the ISS. These equally spaced clamps further strengthened the connection between the ATV and the ISS during the docked phase. The crew now take a cap off an ATV depressurisation valve, carry out a final inspection of the interhatch area and close the ISS hatch. A pressure sensor is hereafter installed on the ISS hatch, the area between the hatches is depressurised (controlled by the ATV Control Centre), and a leak check is performed by the ISS crew.

2 to 4 Orbits Before Undocking

In the last 2 to 4 orbits before undocking, certain parameters are updated in ATV systems by the ATV Control Centre in order to carry out and follow the correct flight profile for undocking, deorbit and re-entry. This includes updating the mass properties (mass, centre of gravity and inertia). The mass properties take into account, waste cargo transferred into the ATV, cargo transferred out of the ATV and ATV propellant consumption due to ISS reboost, attitude control and debris avoidance operations.

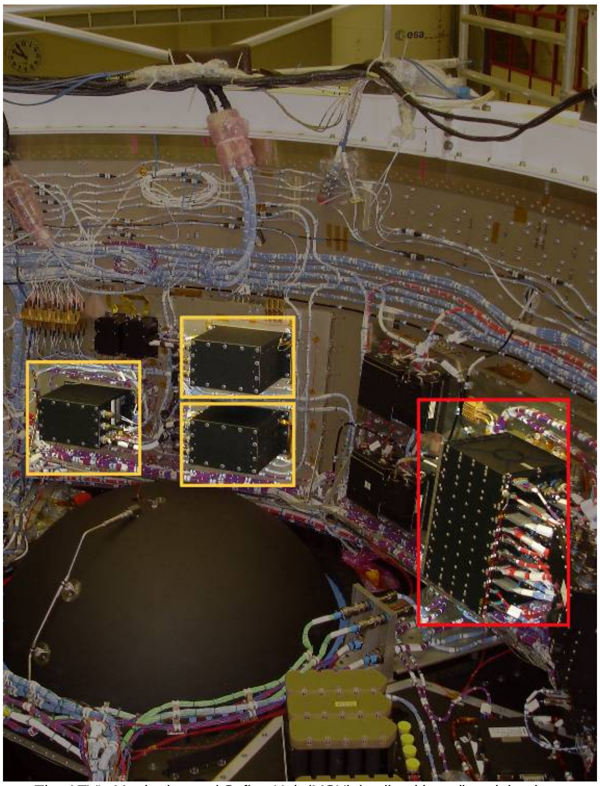
The ATV Control Centre in Toulouse has responsibility to update ATV system parameters, and preparing and uploading mission plans for ATV undocking and orbital flight prior to departure. (Image: ESA)

These mass properties have an important influence on ATV guidance, navigation and control. The ATV's Guidance Navigation and Control systems also have updates to the GPS almanacs, which are necessary to help correctly determine the ATV's absolute position and velocity when in free flight.

The crew carry out a final check to make sure that the interhatch area between the ATV and the ISS is depressurised. Once this has occurred the ISS hooks are commanded to open. It is now only the ATV hooks that are keeping the ATV attached to the Station. During this procedure the thrusters of the Zvezda Service Module are inhibited and attitude control of the ISS is carried out by the Control Moment Gyroscopes located on the US segment of the Station. Once the hooks are open, ISS attitude control goes back to being thruster assisted.

The onboard mission plan defining the ATV's flight profile for departure is now prepared and uploaded to the ATV's systems from the ATV Control Centre. This plan includes many parameters relating to orbital position, navigation initialisation, and Sun aspect angle for example.

Vital ATV systems are powered on, which include: the accelerometers and gyroscopes, which are important for ATV guidance, navigation and control; and the ATV's Monitoring and Safety Unit, which acts as a backup to the ATV's primary system upon detection of a critical failure or an unsafe situation.



The ATV's Monitoring and Safing Unit (MSU) (outlined in red) and the three electronic boxes (outlined in yellow) for the Fault Tolerant Computer (FTC) inside Jules Verne ATV avionics bay. The triple FTC, which is the main computer, plays the role of a pilot that navigates the ATV. The Monitoring and Safing Unit (MSU) can be compared to a pilot responsible for safety, hidden inside the automated spaceship responsible for the mission.

A GPS update of orbital position is carried out so that the ATV can quicker obtain communication links with GPS satellites as these systems were deactivated during the attached phase of the ATV with the ISS.

Last Orbit Before Undocking

With one orbit remaining until undocking the ISS Proximity Communication Equipment is switched on so that the ISS can communicate with the ATV after undocking. For the last time of the Jules Verne mission ISS attitude control is performed by ATV, which will turn the ISS to the correct attitude required for undocking. This is called Local Vertical, Local Horizontal and can be compared to the horizontal flight profile of an airplane, with the ATV at the back of the ISS, the European-developed Node 2 at the front and the truss supporting the large solar arrays extending horizontally out in the direction of an airplane's wings. Once in the correct attitude ISS takes over attitude control again to keep the ISS in the Local Vertical, Local Horizontal attitude

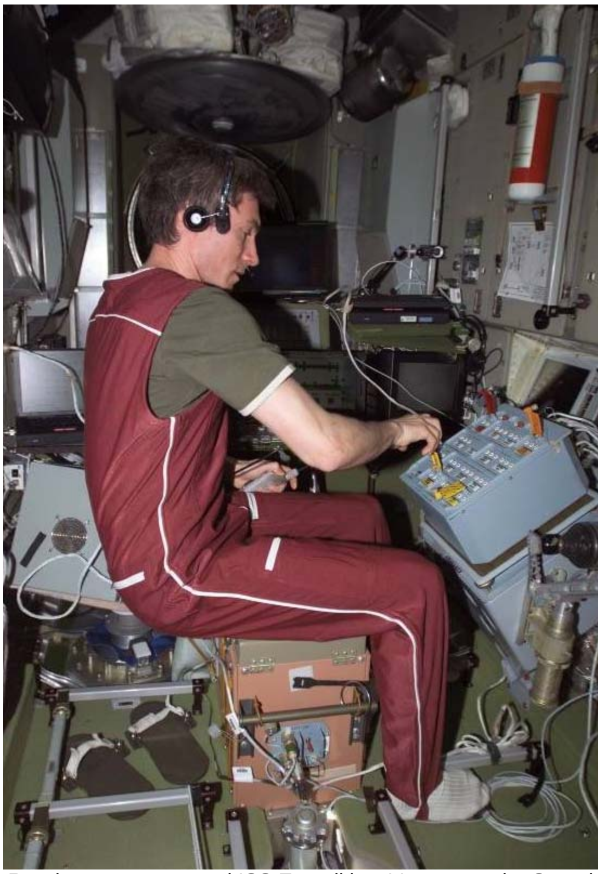
For undocking the Station will be tilted by a few degrees, front to back, with the ATV situated at the back of the Station. (Image: NASA)

One minute after undocking, the Station will return to its previous orientation, called Torque Equilibrium Attitude, which is tilted by a few degrees from front to back when compared to the undocking profile. This reduces the torques on the Station for more effective attitude control.

The ATV Control Centre upload a series of parameters to the Monitoring and Safing Unit so that, during undocking and separation, the ATV can safely undertake a Collision Avoidance Manoeuvre in the unlikely event that a major failure occurs in the Fault Tolerant Computers which run Guidance, Navigation and Control for the ATV.

With 28 minutes remaining before undocking the ATV's avionics systems are woken up and the ATV's propulsion systems are configured for departure.

The crew carry out a final test on the Proximity Communication Equipment to make sure that all functions work. With 20 minutes until undocking the ATV is fully reactivated. Once all ATV on-board systems are ready and communication between the ATV and the ATV Control Centre is available, the ATV propulsion system is activated. Communication/data transfer between the ATV and the ISS is switched through to the Proximity Communication Equipment and the ATV is switched to autonomous power.



Russian cosmonaut and ISS Expedition 11 commander Sergei Krikalev testing the ATV's Proximity Communications Equipment in the Zvezda Service Module of the ISS in June 2005 in preparation for the future arrival of the ATV. (Image: NASA)

Once the Russian Docking System is activated and the ISS monitoring equipment is ready and switched on (also used by the crew to monitor ATV during rendezvous and docking), electrical, fluid and data lines are disconnected between the ATV and the ISS. Two minutes before ATV hooks opening, the ISS attitude control is disabled, putting the ISS in free drift, so that there are no thruster impulses from the Station before and during separation.

Undocking and Departure Sequence

As with rendezvous and docking, the ATV Control Centre is monitoring every moment of undocking and separation and has the capability to initiate a Collision Avoidance Manoeuvre. This is further backed up by the ATV's automatic systems and the ISS crew who can use the ATV Control Panel in the Zvezda Service Module to initiate such a manoeuvre after undocking. The ISS crew will be monitoring the undocking using special equipment inside the ISS.

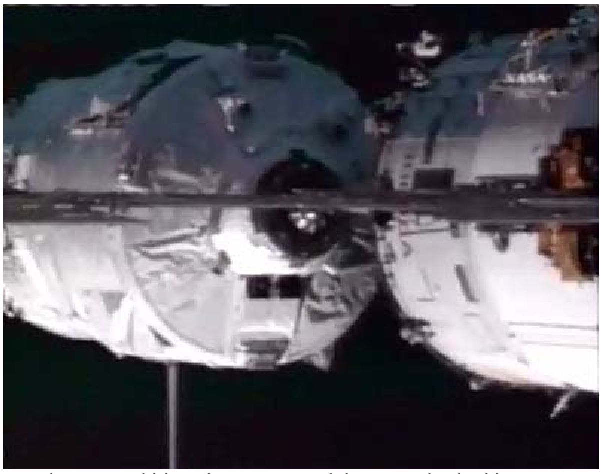
NASA astronaut and ISS 16 Commander Peggy Whitson and Russian Cosmonaut and Expedition 16 Flight Engineer Yuri Malenchenko monitoring the ATV on screens in the Zvezda Service Module (during docking) on 3 April 2008.

With all relevant systems primed and ready the go command is given from the ATV Control Centre and the ATV hooks are opened causing undocking. This is currently scheduled to occur on 5 September at 23:29 CEST.

The ATV is slowly pushed away from the ISS by a spring mechanism on the Zvezda docking port. The European logistics spacecraft is in free drift as it moves slowly away from the ISS at a speed of 5cm/s. The ATV's automatic Collision Avoidance Manoeuvre system is now enabled by the ATV-Control Centre and starts flight control monitoring.

One minute after undocking the ATV is at a distance of 3 metres from the ISS. At this point the nominal departure thrust begins, moving it away from the ISS (and slowing it down) up to a relative speed of 4m/s. The ATV thruster firings are computed on-board based on the ATV orientation.

For the 5-minute departure thrust the ATV uses its smaller attitude control thrusters.



The ATV within a few metres of the Zvezda docking port (shown here during docking). After being pushed away from the ISS on undocking the ATV will start its departure boost. (Image: ESA)

At 22 minutes after undocking ATV passes under the ISS at an altitude of 5 km. The ATV is now in a so-called Yaw Steering attitude, which provides the optimum orientation of ATV with respect to the Sun for power generation by ATV Solar Arrays when ATV is in sunlight.

The ATV is now at a safe enough distance, and the ATV Control Centre can now disable the Automatic Collision Avoidance Manoeuvre system, the Monitoring and Safety Unit and the Proximity Communication Equipment link between the ISS and the ATV. The Orbital Control Frame is also activated. This is a part of the Guidance, Navigation and Control software that calculates a simple but accurate model of the ATV's flight profile for the following several orbits. This uses data regularly updated from the ATV Control Centre.

ATV Re-phasing

With the departure phase complete the ATV now goes through a re-phasing period, which lasts just over 23 days and brings the ATV to a specific point 1725 km behind and between 20-25 km below the ISS to start re-entry procedures.

Artist's impression of the ATV in orbit. (Image: ESA/D. Ducros)

29 September is the first day allowing ATV re-entry over the South Pacific during local night, which is a key requirement for re-entry observation by scientific instruments installed on aircraft and also on-board the ISS. A series of manoeuvres will be computed by the ATV Control Centre experts to ensure arrival of ATV at the right point and the right time. ATV Control Centre experts also ensure that the manoeuvres are optimised to minimise the propellant consumption. During this stage the Russian Progress 30P spacecraft will be in Low Earth Orbit on its way to the ISS following a launch scheduled for 10 September. It will dock to the ISS on 12 September at the same port where the ATV has been docked for 5 months. This is monitored by ATV Control Centre experts, which could perform an avoidance manoeuvre in the unlikely case that ATV and 30P would come to a collision course.

On 15 September, after being in free drift for many days the ATV Control Centre commands Hohmann-like transfer manoeuvres to reduce orbital altitude. To do this the ATV uses its main aft thrusters to carry out two retrograde thruster firings at specific points on its orbit. This slows the spacecraft down and quickly lowers the ATV's orbital altitude below the ISS by almost 30 km to over 35 km.

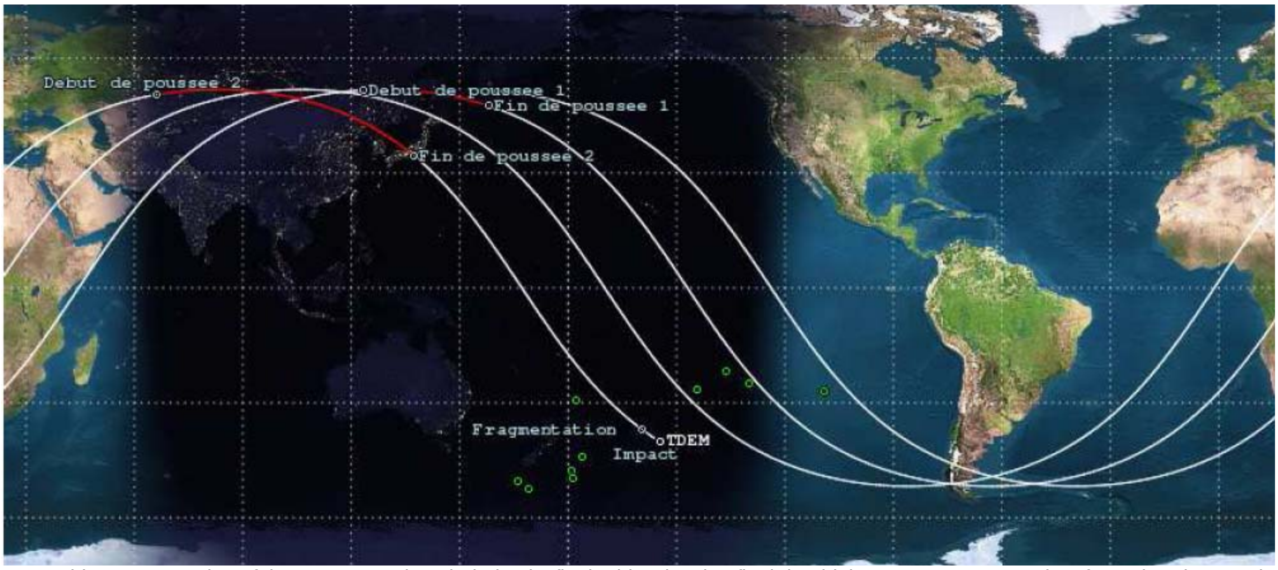
Over the next 12 days the ATV spends many orbits in free flight and its altitude is steadily falling due to atmospheric drag (as is that of the ISS). On 17 September the ATV then undertakes additional manoeuvres computed by ATV-CC using its attitude control thrusters to compensate for any slight deviations from the ATV's planned orbital profile from its previous thruster firings and in its relative orbital profile with the ISS. The ATV will again go through a drift period for one week followed by another set of orbital manoeuvres to correct the ATV's orbital profile mainly in relation to ISS trajectory (i.e. to bring the ATV's orbit more in line with that of the ISS).

Aligning the orbits of the ATV and the ISS during this period has to take many aspects into account such as the differential between the orbiting times of the ATV and the ISS and differences in atmospheric drag at the different altitudes.

With these manoeuvres complete the ATV will carry out additional Hohmann-like manoeuvres to bring it to the correct location and altitude to start re-entry procedures. The first of these manoeuvres, after another drift period of three days, is to transfer the ATV to the appropriate vicinity below the ISS. Two thruster firings will increase speed of the ATV by 2.55 m/s each.

The last manoeuvre rectifies any final deviations in the planned orbital profile, transferring the ATV to the interface point where it will begin deorbit/re-entry procedures. For these manoeuvres the ATV fires its attitude control thruster that will increase the ATV's velocity by 1.7 m/s each. The ATV will reach the interface point just over one day before re-entry. These last two manoeuvres will raise the orbit of the ATV by around 15 km, but it will still be between 20-25 km below the ISS.

Deorbit and Re-entry



Graphic representation of the ATV ground track during its final orbits showing final deorbit burn manoeuvres, point of ATV break up and possible impact of residual ATV elements in the South Pacific. (Image: ESA)

On 29 September the ATV will be put into a planned destructive trajectory into Earth's atmosphere where it will break up and any remaining fragments will fall into an unpopulated area over the South Pacific Ocean. Deorbiting has to take many issues into account. These include having the deorbit boosts last less than 30 mins and the altitude during the intermediate orbits not being below 200 km so as to not degrade the solar arrays.

Prior to re-entry, maritime and air traffic authorities are provided with trajectory details to warn maritime and air traffic about re-entry time and area and recommend avoiding this area during ATV re-entry. The ATV will perform two deorbit burns to re-enter the atmosphere. At least two orbits before the ATV starts its first deorbit burn the ATV Control Centre team analyse the ATV's current orbital profile and calculate the first deorbit manoeuvre to take place. This is uploaded to the ATV. One orbit after arriving at the point where deorbit re-entry procedures start, 1725 km behind the ISS and at an altitude around 330 km (20-25 km below the ISS), the ATV targets the ground track for re-entry. A first thruster firing currently planned just after 12:10 CEST and lasting 6 minutes reduces the ATV's velocity by almost 30 m/s. This makes the ATV's near circular orbit more elliptical, reducing the lower orbiting altitude by almost 100 km to 220 km (The higher altitude remains around 330 km).

With the first burn complete the ATV Control Centre calculate the second deorbit manoeuvre to take place based on the ATV's current orbital profile. This is once again uploaded to the ATV. Two orbits after the first deorbit burn, with the ATV about 14 km behind the ISS, the final thruster burn lasting about 14 minutes occurs at just before 15:10 CEST, reducing velicity by 70 m/s and placing the ATV on its re-entry trajectory. After the last burn cut off the ATV is placed in a tumbling motion to avoid any rebound during re-entry and assist in fragmenting the ATV.

Artist's impression of the ATV burning up in Earth's atmosphere at the end its mission. (Image: ESA/D.Ducros)

At almost 19 mins after the end of last deorbit burn the ATV starts to enter the upper atmosphere at 120 km at around 15:40 CEST. As the atmospheric pressure builds the ATV will break up at an altitude of 75 km. Some 11.5 minutes after entering the upper atmosphere the remains of the ATV will fall into the Pacific Ocean bringing the mission to its conclusion.

ATV Re-entry Observation Campaign

A Gulfstream V jet being prepared for an observation campaign of the Quadrantids meteor shower in January 2008. A Gulfstream V will also be used for the ATV re-entry observation campaign (Image: Jürgen Wolf, Karsten Schindler; Deutsches SOFIA Institut (DSI))

The final moments of Jules Verne will be observed in detail by a joint ESA-NASA airborne observation campaign. This will record the spacecraft's re-entry with a range of instruments in order to determine how the ATV breaks up as it passes through Earth's atmosphere as well as specific events such as fuel tank rupture, which could affect how the ATV breaks up. Additionally, simultaneous observations are planned from the ISS. This information is invaluable for comparing with previously developed computer models of the ATV re-entry, which will help to enhance safety assessments of future re-entries of the ATV and other ESA and NASA spacecraft.

Two NASA provided aircraft, fitted out with observation equipment, will be used to observe the Jules Verne ATV during its destructive re-entry, which is planned for 29 September. The re-entry is timed to permit night time observations which are needed to ensure high quality observation data. Assuming this occurs on 29 September, the re-entry would take place at around 15:20 CEST (+/-45 minutes). This is a couple of hours before sunrise local time at the observing location in the South Pacific. The two aircraft, a Gulfstream V and the NASA DC-8, would take off from Tahiti 3-4 hours before re-entry, spending from 6-8 hours in the air.

The aircraft will provide a high altitude (12 - 14 km) platform for observations. This will allow a view of a large part of the ATV trajectory. The observation site is approximately 2000 – 4000km from Tahiti. The Gulfstream V will be positioned near to the point where the ATV will be at an altitude of 60 - 80 km. This position is optimised to observe the most likely major fragmentation event and provides a side view to see deceleration of fragments for measurement of size and composition. The NASA DC-8 will be positioned near the point where the ATV will be at an altitude of 50 - 70 km. This position will optimise observation of the ATV's approach and frontal view of debris fragments for measurement of size, peak heating, and elemental composition. Having two planes in the air for observation purposes not only provides the ability for simultaneous observations, it also provides some redundancy should one of the aircraft have problems or the ATV has a slight alteration in its trajectory due to an under or overboost prior to entry. The observation mission is organised by ESA with operations managed by a NASA Ames Research Center team with extensive prior experience in spacecraft re-entry observations, including the NASA Genesis and Stardust sample return capsule re-entries.

The observation campaign will provide data on a range of aspects of the re-entry such as: characterising the fragmentation of the vehicle, including detection of fragmentation events, identification of likely cause (eg. fuel tank rupture, melting of structure); altitude of each event size and nature of fragments; measure the spin rate of the vehicle and fragments during re-entry; estimate the number, size distribution and velocity changes of fragments breaking off from the ATV; characterise wake emissions and ablation; and reconstruct entry trajectory.

AIMIT tracker and Echelle slit spectrograph during the Genesis capsule re-entry observation campaign in 2004. These instruments will be used during the ATV re-entry campaign.
(Image: NASA Ames Research Center)

A wide range of instruments will be used for observation purposes including telescopic and wide field imagers, HDTV cameras, digital still cameras, photometers and various spectrographs that will work in the near-UV, optical and near-infrared range. The data from some instruments will need special processing. However the conventional video as well as digital stills cameras can be viewed directly. It is expected to observe incandescent fragments and the plasma wake, as well as the star field (for trajectory determination).

The observation planes will be in contact with the ATV Control Centre via satellite phone in order to get confirmation of the two manoeuvres which occur prior to re-entry. The planes will be staffed with personnel from ESA, NASA Ames, The SETI Institute, and other European and American Universities and Institutions.

HDTV spectrograph during the Genesis capsule re-entry observation campaign in 2004. (Image: NASA Ames Research Center)

The aircraft observations are planned to complemented with ultraviolet and visible range observations from instruments on the Russian segment of the ISS. To permit these observations the ATV will be positioned below the ISS at the time of re-entry, as a result of a series of manoeuvres performed between undocking and re-entry.

Jason Hatton, ESA's ATV re-entry observation campaign mission manager operating all sky imagers during observation campaign of the Quadrantids meteor shower in January 2008.
(Image: P. Jenniskens, SETI Institute)

ATV Control Centre, Toulouse, France

(Responsible for ATV operations including deorbit and re-entry)

The Flight Control Room of the ATV Control Centre during Demonstration Day 1 on 29 March 2008. (Image: ESA)

The ATV Control Centre (ATV-CC) is located in the elegant, modern-style Fermat Building of the French Space Agency's (CNES) Toulouse Space Centre. Under contracts signed in 2003, CNES developed the ATV-CC and prepared the operations of the first Automated Transfer Vehicle mission under the management of ESA.

Under the authority of ESA, the ATV-CC teams (flight control, flight dynamics and engineering support): held responsibility for the ATV separating from the upper stage of the Ariane 5 launcher at the start of the mission; monitored and controlled the ATV's orientation and orbital trajectory en-route to and approaching the ISS; and for the concluding step of the mission will command the ATV to separate from the ISS, and carry out a controlled destructive re-entry into Earth's atmosphere over an uninhabited area of the Pacific Ocean.

The ATV-CC has executed all the pre-programmed mission plans so far, implementing any changes as and when needed. The tasks that the ATV-CC has carried out have been challenging ones, requiring a very high degree of technical skill, especially since this has been the first time that Europe has accomplished these kinds of operations.

The first ATV mission has required complex interactions and shared responsibilities between control centres dispersed throughout the world and this will continue with each ATV mission in the future. The ATV Control Centre worked first with the Guiana Space Centre, in charge of launch and deployment of the ATV. For undocking, as was the case with rendezvous and docking, the ATV Control Centre will work in close coordination with the Mission Control Centres in Moscow and Houston. All the ATV ground control commands are issued from Toulouse. For example, in case of a major malfunction during undocking (as with rendezvous and docking), the ATV Control Centre, as well as the ISS crew, can initiate the Collision Avoidance Manoeuvre to move the spacecraft away from the Station.

Mission Control Centres

To allow continuous coordination with the other control centres and to remain in contact with the ATV during the mission, using the NASA Tracking and Data Relay Satellite System as well as ESA's Artemis relay satellite, the ATV Control Centre will rely on the European ISS ground communication network, which is controlled from the Columbus Control Centre located at DLR, in Oberpfaffenhofen, Germany.

The Columbus Control Centre. (Image: DLR)

Control Rooms and Operations Teams

Four teams work at the ATV Control Centre, in three control rooms:

1. The European Space Agency's ATV Operations Management Team, in charge of the overall operations preparation and execution activities, and of decision making for off-nominal situations;

2. The Flight Control Team, in charge of the ATV operations;

3. The Flight Dynamics Team, which is responsible for monitoring the ATV trajectory and attitude as well as computing manoeuvres.

4. The Engineering Support Team, providing flight analysis and expertise for the whole mission.

The main control room is dedicated to the ATV mission execution/management performed by the CNES flight control team, headed by the flight director. He is in charge of the real time decisions in coordination with the ESA ATV Mission Director, who sits along side the CNES Flight Director.

Teams at work in the ATV Control Centre. (Image: CNES/B. Guindre)

The Flight Dynamics Control room, is home to the CNES flight dynamics team.

The third room houses an Engineering Support Team comprising experts from ESA and EADS-Astrium (the ATV prime contractor) who are ready to support the flight controllers in case of problems with the ATV systems. The engineering support team gets involved when something is not working as expected. Since these development engineers are experts in the ATV systems, they are able to advise the flight control team on corrective measures in case of a failure.

Mission Control Centre – Moscow, Russia

(Responsible for Russian ISS modules and Soyuz/Progress spacecraft)

ISS Control Room at the Mission Control Centre in Korolev near Moscow. (Image: NASA)

For ATV missions, The Russian Mission Control Centre is the mission authority for all ATV-ISS joint operations (rendezvous, attached phase active operations, etc.) and has been responsible for controlling the ISS during the run-up to ATV rendezvous, for providing the interface with the ISS crew and for controlling ATV for all attached active operations with the ISS including the four Station reboosts that were carried out during the ATV docked phase, and a debris avoidance manoeuvre on 27 August.

The control centre, known as TsUP in Russian, is situated in Korolev (formerly Kaliningrad) near Moscow. TsNIIMash, the Russian acronym for the Central Research Institute for Machine Building, operates the facility on behalf of the Russian Federal Space Agency, Roscosmos. The ISS flight control teams are provided by RSC-Energia.

TsUP was built in 1973 and was used as the Mission Control Centre of the Mir and Salyut space stations and houses the flight control rooms for the Progress and Soyuz launches.

Mission Control Center – Houston, Texas, USA

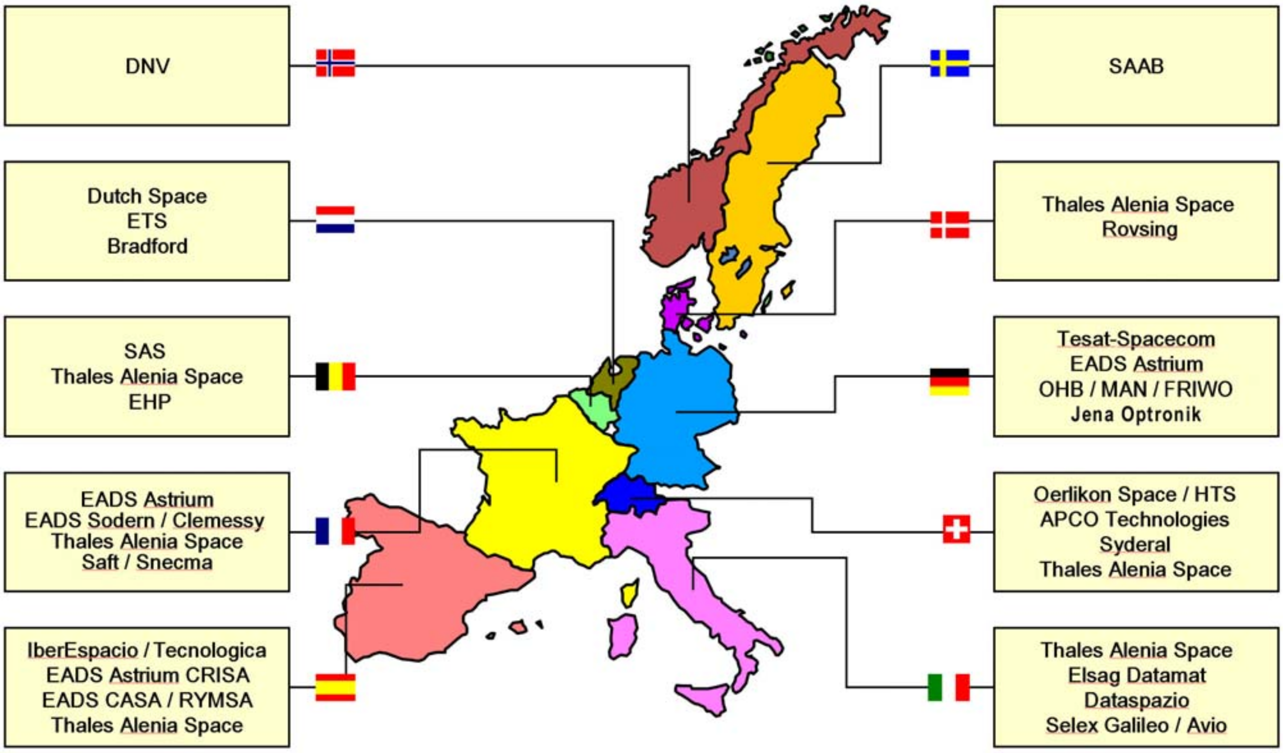
(Overall Control of ISS activities)

ISS Flight Control Room at the Mission Control Center in Houston, Texas during the transfer of ESA's Columbus laboratory from Space Shuttle Atlantis to the European-built Node 2 of the International Space Station on 11 February 2008. (Image: NASA)

The NASA Mission Control Center, located at the Lyndon B. Johnson Space Center in Houston, Texas has been the heart of NASA Human Spaceflight operations since 1965. There are different Flight Control Rooms at the control centre covering ISS Operations and Shuttle flights. The ISS Flight Control Room began operations on 20 November 1998. It acts as the command and coordination centre for all ISS activities, including ISS flight control.

For ATV missions, Mission Control – Houston has overall ISS mission authority and coordination responsibility. It has responsibility for overall ISS safety and leading the investigation of anomalies as well as for providing Tracking and Data Relay Satellite services for the ATV mission.

ATV Industrial Team



Geographical distribution of ATV industrial team in Europe

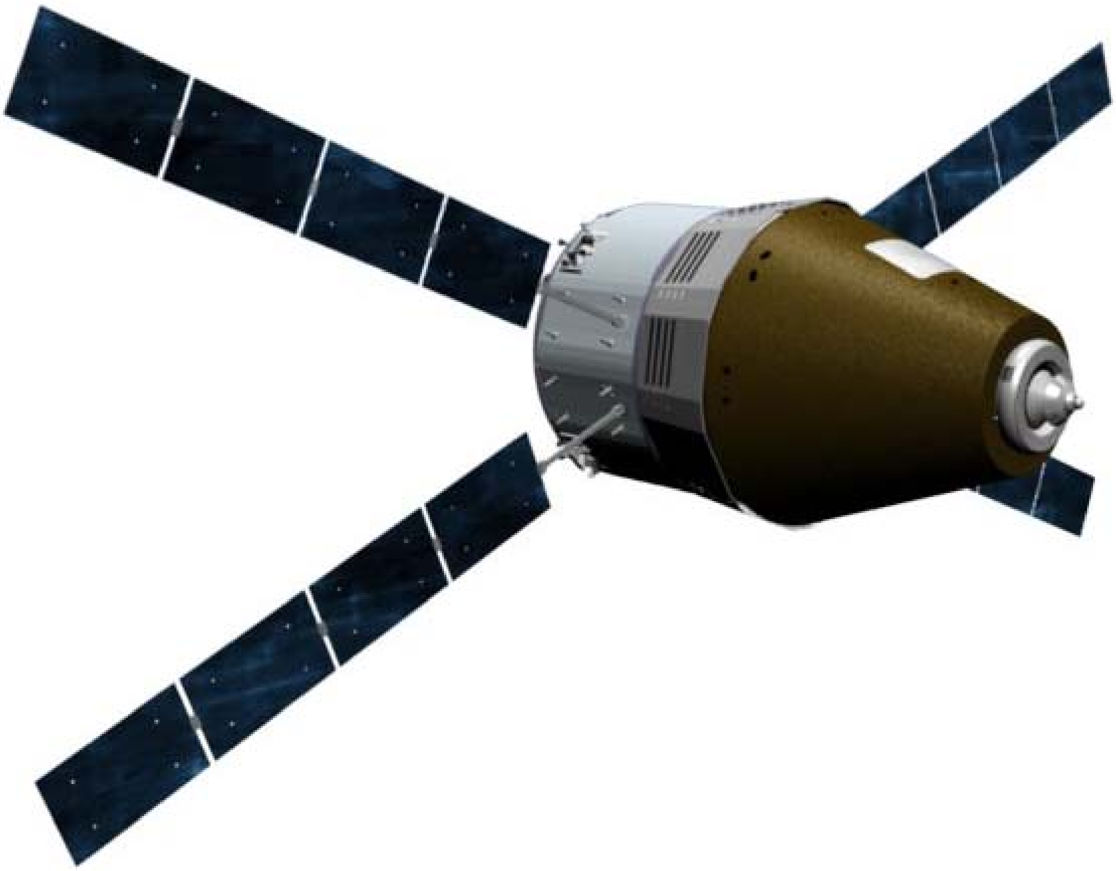
The ATV is part of the European participation in the ISS which is an optional ESA programme. Ten of the ESA Member States have decided to participate in ISS project and, as such, are also involved in the ATV.

Each country decides in which optional programme they wish to participate and the amount of their contribution. ESA operates on the basis of geographical return, i.e. it invests in each Member State, through industrial contracts for space programmes, an amount corresponding to each country's contribution.

The ATV project involves dozens of companies and thousands of technicians and engineers from ten European countries under the prime contractorship of EADS Astrium (formerly EADS Space Transportation in France prior to reintegration into EADS Astrium). In addition to the business units (Astrium Space Transportation and Astrium Satellites) and subsidiaries of EADS, the European companies also involved in the ATV programme include Thales Alenia Space, Oerlikon Space, Dutch Space (now part of EADS Astrium), Snecma (part of the SAFRAN group), MAN and many others.

The project also includes the cooperation of a number of Russian companies, whose main contractor is RSC Energia, which has built the ATV docking mechanism, the refuelling system and the associated electronics. The programme also involves the cooperation and a number of US companies.

ATV Evolution: Advanced Re-entry Vehicle



Artist's impression of The Advanced Re-entry Vehicle approaching the ISS (Image: Thales Alenia Space)

The very successful Jules Verne ATV mission has highlighted many new technologies and capabilities that can be utilised and adapted in the future for developing new spacecraft, which also make use of additional European know-how, such as atmospheric re-entry technologies. Such development could be of great strategic importance for Europe's role in human spaceflight endeavours in low earth orbit and for future exploration missions, leading to an autonomous launch and return capabilities to and from orbit.

The ATV currently has a capability to re-supply the ISS with up to 7.5 tonnes of propellants and cargo, and is the largest orbiting space vehicle beside the US Space Shuttle. With the Space Shuttle retirement planned in 2010, the ISS partners will lose a major capability to return heavy equipment to Earth for replacement or upgrade. Following on from previous studies, the next logical step will be the capability to return payloads and goods from the ISS and any future orbital infrastructure.

Advanced Re-entry Vehicle

In this scenario the pressurised front cargo section of the ATV (the Integrated Cargo Carrier) would be replaced by a cargo re-entry capsule equipped with a heat shield and able to bring back hundreds of kg of cargo and valuable experiments. Such a project could use the heritage of the Atmospheric Re-entry Demonstrator, which flew successfully in 1998, as well as the work carried out in the period 1998-2002 on the Crew Return Vehicle for the ISS and associated technologies.

This system will use an updated service module, propulsion system, and similar rendezvous and docking technology as the present ATV. The development of a new cargo transportation and re-entry capsule will complete the new vehicle. This spacecraft could be operational by 2015 and as such could provide a valuable service to the International Space Station in payload upload and download. The spacecraft would use the Ariane 5 ES launch vehicle for such missions with a modified fairing.

The Atmospheric Re-entry Demonstrator

Future Developments: Crew Transportation
Once the capability of bringing back cargo from space has been demonstrated, such a spacecraft could undertake the next logical step: a European crew transportation system, which would require more complex modifications and additional technologies.

The service module would require further upgrades including an improved propulsion system and the addition of the subsystems supporting the crew presence and operations. The upper part of the Advanced Re-entry Vehicle would be transformed into a human rated re-entry capsule. The new transportation system could be launched on a suitably modified version of Ariane 5.

This second-step vehicle would require additional developments in flight safety, especially for a guided crew escape system during launch and life support subsystems. This crew escape system would consist of solid rocket motors able to pull the crew capsule away from the launcher in the event of an emergency. It would have the capability to accommodate four astronauts and could be operational by 2020.

Artist's impression of the crew version of the Advanced Re-entry Vehicle in launch configuration on an Ariane 5. The spacecraft is in its fairing with a crew escape system located at the top of the stack (image: ESA/D. Ducros)

For both the manned and unmanned versions of the Advance Re-entry Vehicle, the most likely scenario is that the return module would ditch in water, probably in the Atlantic Ocean off the European coast.

The principle of this spacecraft could be used in support to future orbital infrastructures, and could be the basis for successive modifications in support to future exploration missions.

Credits

This document has been compiled, produced and written by the Coordination Office of the European Space Agency's Directorate of Human Spaceflight in Noordwijk, The Netherlands. It has been compiled from internal ESA sources with additional images and information kindly supplied by the following organisations:

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