

ATV will extend Europe's influence on ISS

# The ultimate space tug

by Clive Simpson

Jules Verne pioneered the science fiction genre with visionary novels such as *Journey to the Centre of the Earth*, *Twenty Thousand Leagues Under the Sea* and *Around the World in Eighty Days*. The celebrated 19th century French author was writing about space, air and underwater travel before such things were invented. Today, a century after his death, 'Jules Verne' stands on the brink of flight.

What then might one of the father's of science fiction have made of Europe's latest venture into space - the long-awaited Automated Transfer Vehicle (ATV), a space tug and cargo craft resembling a giant cylindrical bin with wings, the first of which is named in honour of the celebrated author?

ESA's project manager John Ellwood describes the ATV craft as "the most complex and innovative spaceship ever developed and built in Europe".

The ATV's rather unglamorous but essential mission will be to service the International Space Station (ISS) as a cargo carrier, storage facility and as a 'tug' vehicle to raise the Station's constantly degrading orbit every so often.

The Space Station's lifeblood comprises regular deliveries of experimental equipment and spare parts as well as food, air and water for the permanent crews. At present this role is largely fulfilled by the US Space Shuttle and Russian unmanned Progress craft, but the retirement of the Shuttle in 2010 will give added importance to Europe's ATV.

Each of the new craft (there could be up to seven) will be launched by an Ariane 5 from Europe's spaceport in Kourou, French Guiana, and carry up to nine tonnes of cargo on a mission typically lasting six months.

This much delayed inaugural flight after an extensive three year test campaign is now set for the second half of 2007, the exact launch date still partly dependent on how this year's already re-jigged Space Shuttle missions fit together.

The hardware for Jules Verne is fully assembled and ready to fly. Now contractors and ESA teams are working overtime to complete testing of the complex spaceship.

This summer the state-of-the-art programme faces three key concurrent objectives - to fully prepare for flight operations, to fine-tune the interfaces with the International Space Station and its partners, and to prepare Ariane 5 for launching its largest payload to date.

## ATV testing

During 2006 and early 2007 the main challenge of ATV qualification testing was to run parallel test campaigns involving a variety of interfaces with different partners. The primary objective of this strategy is to ensure that ATV's hardware and software can handle all possible normal or emergency scenarios that Jules Verne might face during its flight.

For example, at the RSC-Energia plant outside Moscow - the manufacturing site for the ATV docking mechanism, the refuelling system and the associated electronics - major computer simulations took place between December and March at the 'Ground Debugging Complex', with a powerful simulator introducing failure scenarios that the ATV must be able cope with on a real flight.

At the same Russian plant this spring, another two month campaign has been testing real interfaces with a massive replica of the 12.6 m long Russian module at the Control and Testing Station facility.

Thanks to actual physical interfaces, it is possible to test the Russian docking and refuelling system with real fluids and pressurised tanks. Jules Verne, like the Russian Progress vehicle, has the capability to refuel the Station with 860 kg of propellant and evacuate 840 kg of liquid waste.

Meanwhile, at ESA's European Space



Research and Technology Centre (ESTEC), in Noordwijk, the Netherlands, the Jules Verne spaceship underwent two major environment tests during 2006.

The first one was the acoustic test, to verify the capability of the spacecraft to withstand the noise loads experienced during launch.

Next came a thermal vacuum test to verify that Jules Verne, in active status, is able to sustain the harsh space conditions with extreme temperatures in a vacuum. Despite the readiness of the spacecraft itself, this test had to be postponed due to the under-estimated time needed to define precisely the test procedures - which must be perfect - when the flight hardware is involved. Eventually, just a week before Christmas last year, Jules Verne went through this test successfully.

Thanks to Europe's largest ship hull test facility, located west of Paris, the Jules Verne rendezvous technique was tested successfully last autumn. For the first time the system worked in complete 'closed-loop' conditions where all aspects of the spacecraft were either represented for real - computers, software, sensors, trajectories - or simulated such as Jules Verne's inertia, thruster firing etc.

Several mission scenarios will require complex interactions and shared responsibilities between the ATV Control



*Artist's impression of the ATV docked with the Russian Zvezda module.*  
ESA-D. Ducros



ESA/A. Le Floch'h

*Jules Verne ATV undergoing tests in the Large Space Simulator at ESTEC in the Netherlands.*

Centre (ATV-CC) in Toulouse, France, and Russian and American mission control centres in Moscow and Houston.

### Control centres

The launch of Jules Verne means that, for the first time in space history, three space control centres around the globe must work together.

For these joint activities related to the ATV in orbit, specific high-level procedures have been developed, allocating the tasks to be performed sequentially to the centres involved. A dozen simulations involving the three centres remain ongoing to fine-tune the procedures for both nominal and emergency

scenarios that Jules Verne could face.

At the same time, the ISS Expedition 16 crew of Yuri Malenchenko and Peggy Whitson have undertaken specific ATV training at the European Astronaut Centre in Cologne, Germany.

"Their task during rendezvous will be similar to that of an aircraft crew monitoring an auto-land involving 14 different parameters, with no back-up manual control

except the possibility to command an automatic go-around manoeuvre," said ESA astronaut Jean-François Clervoy, senior advisor to the ATV programme.

It is planned to have Jules Verne ready for shipment to the launch site in French Guiana later this summer. The transportation of ATV and its 400 tonnes of ground support equipment from ESA's test centre in the Netherlands to Kourou will take two weeks by sea on board the Ariane 5 transportation ship, Toucan.

"It is very encouraging to see that most of the problems we have encountered are now solved," said John Ellwood. "Although we still have plenty of work to do, we can foresee that we will be ready to ship Jules Verne to French Guiana in the next few months ready for the launch."

*A 120 tonne mobile platform (left), mounted with a set of passive rendezvous targets (retroreflectors) identical to the ones installed on the ISS, facing the sensors mounted on an articulated industrial robotic arm (right). The relative motion achieved between the two is identical to that expected during rendezvous between the first Automated Transfer Vehicle Jules Verne and the Space Station.*  
ESA/S. Corvaja





*During its final approach the ATV will set up a direct link with the Space Station, allowing it to initiate relative and accurate navigation as well as using GPS data. As it gets closer to its objective, the ATV ground controllers in Toulouse will direct it on a step-by-step pre-defined approach. This will require authorisation from the Mission Control Centre in Moscow – because it docks on the Russian Zvezda module – and an overall coordination with Mission Control Centre in Houston, which is responsible for the entire Space Station. For each of these steps, the ATV performs automated manoeuvres.*

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## Launch campaign

Since the ATV is the heaviest and most complex spacecraft project ever developed in Europe the first launch campaign in French Guiana will extend over several months.

Besides the readiness of Jules Verne and its control centre, numerous external constraints considerably limit the first ATV's docking date opportunities, which in turn reduce the launch date opportunities.

One major natural constraint is given by the Sun angle with respect to the ATV-ISS line of sight during the final approach. This angle must be low enough to maintain a proper power supply to the ISS and high enough to avoid dazzling the rendezvous sensors. This constraint leaves just two launch windows in 2007, one in September and another in November.

Other major constraints are driven by the traffic of other space vehicles to and from the Space Station and the availability of the docking port usually taken by a Russian re-supply ship Progress.

An unfortunate weather event has also reshuffled the already intricate Jules Verne launch date equation. The hail damage incurred by the Space Shuttle's External Tank on the launch pad in Florida in February has already impacted the Shuttle flight manifest.

Taking into account on the one hand the delays encountered recently by the test teams in Russia and in Europe, due to now resolved problems, and the addition of external constraints on the possible launch dates, the first possible Jules Verne launch opportunities are not earlier than September with a likely schedule slip to November, depending on the resolution of the Shuttle manifest re-planning and the priority given to ATV to re-supply the Station.

## ATV mission

Equipped with its own propulsion and navigation systems, the ATV is multi-functional, combining the fully automatic capabilities of an unmanned vehicle with human spacecraft safety requirements necessary for docking with the ISS.

An on board high precision navigation system will guide the ATV on a rendezvous trajectory towards the Space Station where it will automatically dock to the Russian service module.

It will remain there as a pressurised and integral part of the complex for up to six months until departing for a controlled re-entry into the Earth's atmosphere where it will burn up and, in the process, dispose of waste material no longer needed on the Space Station.

ATV's cylindrical shape – 10.3 m long and 4.5 m in diameter – is covered with an insulating foil layer on top of meteorite protection panels. Its x-shaped solar arrays resemble metallic blue wings and give it a characteristic 'dragon fly' look.

Internally, the ATV consists of two modules, the avionics/propulsion module, called the ATV Service Module, and the Cargo Carrier, which docks with the ISS.

Although people will not be launched in an ATV, astronauts dressed in normal clothing will be able to access cargo and systems during the time it is docked.

The 45 m<sup>3</sup> pressurised volume of the Integrated Cargo Carrier is based on the Columbus laboratory, which in turn is based on the Italian-built Multi-Purpose Logistics Module (MPLM).

Each ATV will have room for up to eight racks loaded with modular storage cargo elements as well as carrying several tanks containing drinking water, refuelling

propellant for the Space Station's own propulsion system and air (oxygen and nitrogen) for the crew. The 'nose' of the cargo section contains the Russian-made docking equipment and the rendezvous sensors.

The ATV Service Module navigates with four main engines and 28 smaller ones for attitude control. After docking, it can perform Space Station attitude control, including debris avoidance manoeuvres. It can also de-saturate the Station's gyroscopic attitude system and boost the complex's orbit to overcome the effects of atmospheric drag.

The ATV has about three times the payload capability of its Russian counterpart – the Progress-M cargo vehicle.

## Flight scenario

A typical ATV mission will begin when the craft is launched into orbit by an Ariane 5 from French Guiana.

After separation from Ariane, its navigation systems are activated and engines fired to boost it into transfer orbit.

The cargo craft will normally come into sight of the Space Station after three days in orbit when its computers will begin final approach manoeuvres over the next two orbits, closing with the Space Station at a relative speed of a few centimetres a second whilst both vehicles orbit at around 28,000 kilometres an hour.

Docking will be fully automatic and, if there are any last minute problems, either the ATV's computers or the Space Station crew can trigger a pre-programmed sequence of anti-collision manoeuvres, which would be fully independent of the main navigation system.

With the ATV securely attached, astronauts can enter the cargo section and remove the payload – maintenance supplies, science hardware, parcels of fresh food, and personal mail.

Its fuel and water supply tanks will be

connected to the Space Station's own plumbing system and astronauts will manually release oxygen and nitrogen directly into the ISS.

ATVs will remain at the Space Station for about six months, during which time the crew will steadily fill the cargo section with unwanted material.

Once its re-supply mission is complete, the ATV hatch will be closed by the crew before it is separated automatically. Its engines will de-orbit the spacecraft – not at the shallow angle used for the relatively gentle re-entry of manned vehicles, but on a steep flight path to perform a controlled re-entry under deliberately high forces of atmospheric drag, causing it to break up and burn high above the Pacific Ocean.

## Control and rendezvous

The maiden ATV flight will mark the first rendezvous and docking ever of a European spacecraft in orbit, and also be the first European re-supply mission to the Space Station.

It is the most demanding and complex of the seven planned ATV missions and will take up to ten days – compared to between three and five for a normal mission – a time frame that will allow engineers to perform a series of detailed tests en route.

Among other things, it has to be demonstrated that the 20.7 tonne cargo ship is capable of halting its rendezvous manoeuvre at any time by stopping and flying away from the Space Station.

During the most critical phases of an ATV flight - from launch to docking, and from departure to re-entry - a 60 person team at the ATV Control Centre in Toulouse, France, will work in three adjacent control rooms monitoring closely the fully automatic approach procedures.

The French space agency CNES has responsibility for management of the centre and will coordinate and support all ATV operations on behalf of ESA.

The automatic rendezvous is made possible using a series of instruments, beginning during the orbital flight with a combination of star tracker (which identifies different constellations in the sky and uses this information to calculate its own orientation in space) and GPS data.

The spacecraft uses these to draw closer to the Space Station before switching to a different system for the high precision docking - a videometer's eye-like sensors combined with separate parallel measurement systems.

The videometer will analyse images of its



*ISS Expedition 16 crew Peggy Whitson and Yuri Malenchenko during ATV training at the European Astronaut Centre in Cologne, Germany.*  
ESA/DLR

emitted laser beam reflected by passive retro-reflectors located on the Space Station next to the Russian docking port where the ATV will be attached.

During the last 20 metres of the final approach, the videometer will automatically recognise the retro-reflector's target patterns and then calculate the distance and direction to the docking port.

To add a safety margin a secondary sensor – called a telegoniometer – will emit laser pulses at a different wavelength to the retro-reflectors. The travel time of the pulses gives the distance, and direction is given by the orientation of two built-in mirrors.

The telegoniometer's radar-like pulses

*The ATV dwarfs engineers (lower left) during tests in the acoustic chamber at ESTEC.*

ESA-S.Corvaja



provide 10,000 hits per second, whereas the camera-like videometer illuminates its objective from once per second to 10 times per second as it approaches the target.

## Future developments

ESA sees the ATV as having potential in the future for developing into a variety of new space vehicles.

One study has looked at three scenarios - replacing the pressurised cabin with a cargo return craft and re-entry shield which would be able to bring back cargo and valuable experiments; an unpressurised logistics carrier which could bring several tonnes of equipment not requiring a pressurised environment to the Space Station; and a crew transport vehicle, which would require more complex modifications.

Other future ideas include equipping the core of the ATV with a small ejectable capsule able to return about 150 kg of cargo to Earth at the end of its mission; evolving the ATV towards an unmanned free-flying laboratory able to periodically dock for major servicing support; constructing a mini space station by equipping ATV with two docking mechanisms; and even evolving it into a transfer vehicle carrying tonnes of supplies - including space telescopes and planetary spacecraft - to lunar and Martian orbits.

A future technological legacy indeed - and probably just the kind of vision that would have enthused Jules Verne.