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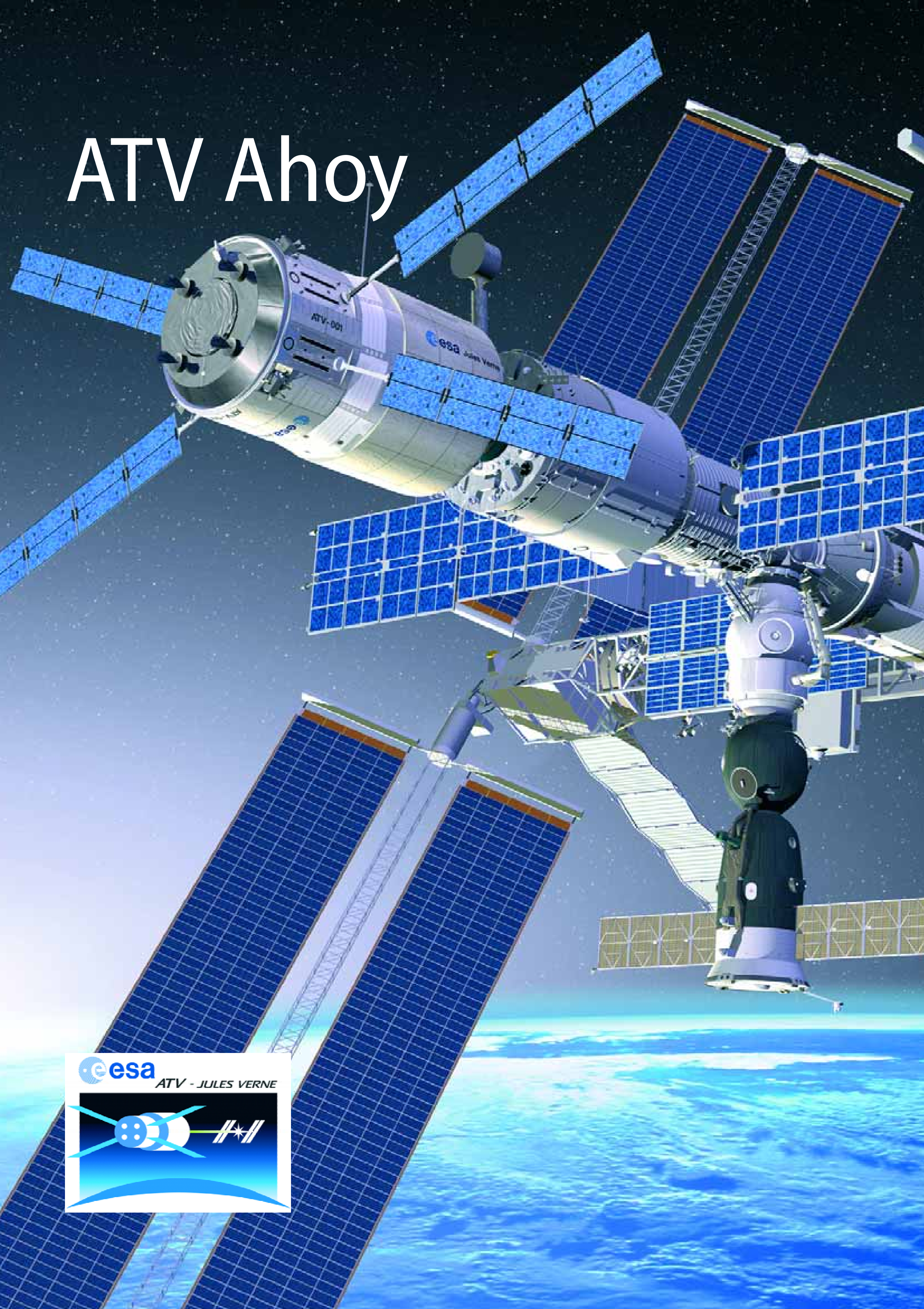

ESA/D. Ducros

Final Preparations for the First Flight of Europe's Space Ferry

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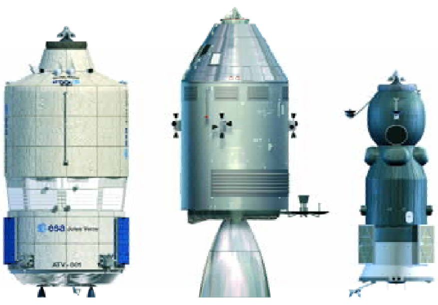
Jules Verne, the first of five Automated Transfer Vehicles (ATVs), stands on the brink of flight. Its inaugural mission, set for the second half of 2007, will conclude an extensive 3-year test campaign. During the coming crucial months, the programme faces three key objectives: prepare for flight, fine-tune the interfaces with the International Space Station and the ISS partners, and ready Ariane-5 for launching its largest payload to date.

Introduction

The ATV marks a new step for European space transportation and lays a cornerstone for human spaceflight. It is the most versatile spacecraft ever developed, uniquely able to self-navigate in orbit and control its own rendezvous. It is a critical resupply tool for the ISS and for the Station partners, especially after Shuttle flights end in 2010 and the ISS must rely on ATV for reboost and disposal at the end of its life.

With ATV technology, ESA has the capacity for automatic rendezvous between spacecraft – crucial for robotic sample-return missions, assembling



ATV's complexity is comparable to that of the Apollo craft that took mankind to the Moon. (ESA/D. Ducros)

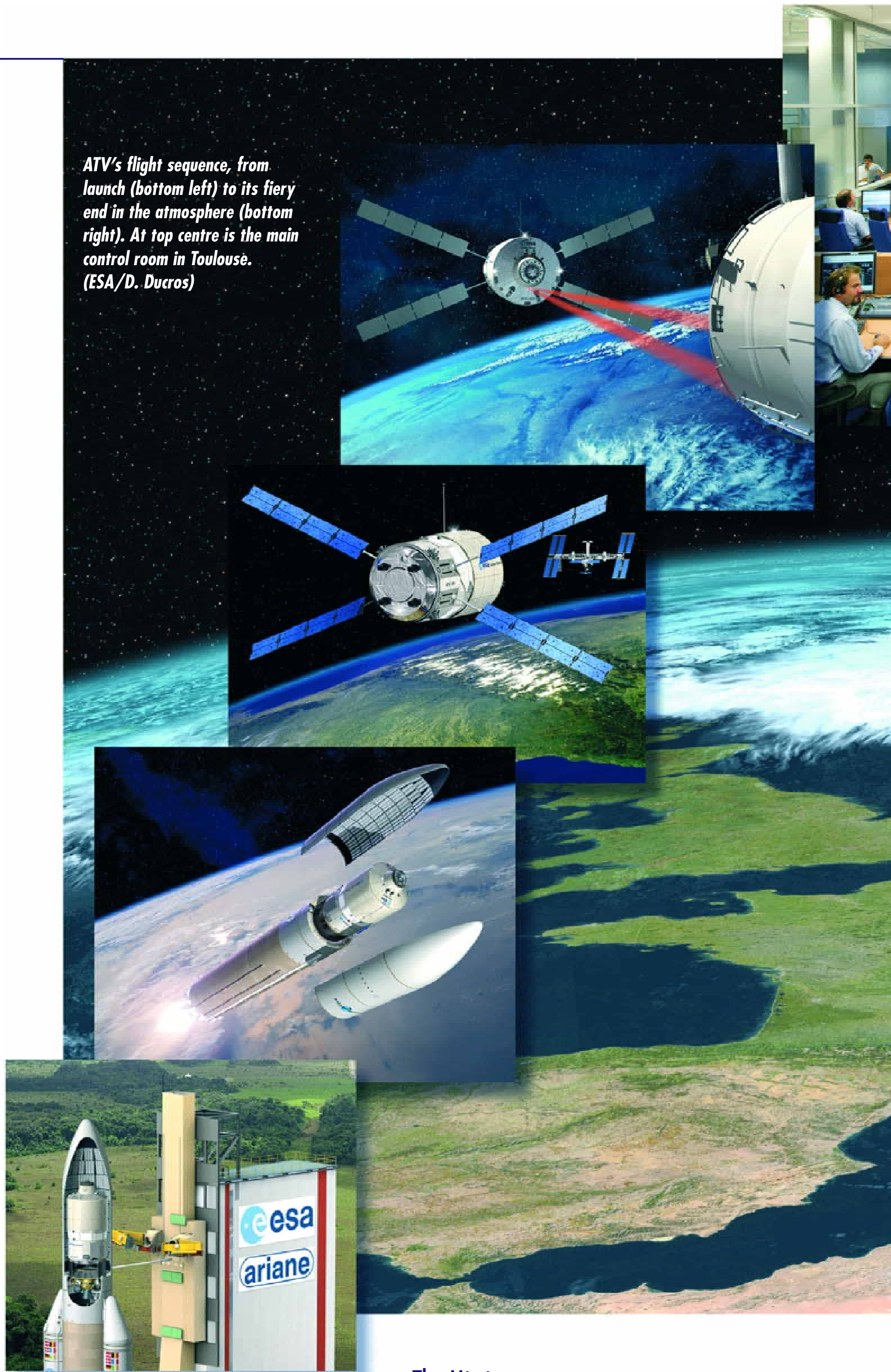
complex spacecraft, and future human planetary exploration.

Several European countries made the political commitment in 1988 to participate in the Station by signing the Inter Governmental Agreement with the USA and other participants. In 1992, ESA began a joint study with NASA to define ATV missions to what was then Space Station *Freedom*. The following year, ESA and the Russian space agency agreed to study possible ATV missions to Mir-2 and, later, to the Russian segment of the ISS.

After numerous political changes in the former USSR and following a US decision in 1993 to include Russia in building the Station, it was finally decided in 1994 to build ATV. In February of that year, the 111th ESA Council Meeting in Paris agreed to the Manned Space Transportation Programme, including ATV. At the Ministerial meeting in Toulouse in October 1995, ATV's full development won formal approval.

For more than a decade, ATV has involved dozens of companies and thousands of engineers from 10 European countries under the prime contractorship of EADS-Astrium Space Transportation (F). The companies include Alcatel Alenia Spazio, Contraves Space, Dutch Space, Snecma, Alcatel Espacio, Crisa and MAN. Eight Russian companies are also involved, with the main contractor, RSC Energia, in charge of building 10% of ATV.

The 19.4 t *Jules Verne* is the most complex space vehicle ever developed in



ATV's flight sequence, from launch (bottom left) to its fiery end in the atmosphere (bottom right). At top centre is the main control room in Toulouse. (ESA/D. Ducros)

Europe. Since summer 2004, it has been assembled and tested at ESTEC, at times requiring new technical solutions, minor changes and a lot of fine-tuning. The technical complexity of the programme has led to a 3-year delay in the inaugural launch. Now, after meeting numerous challenges, *Jules Verne* is in the home strait, aiming for launch in the second half of 2007.

The Mission

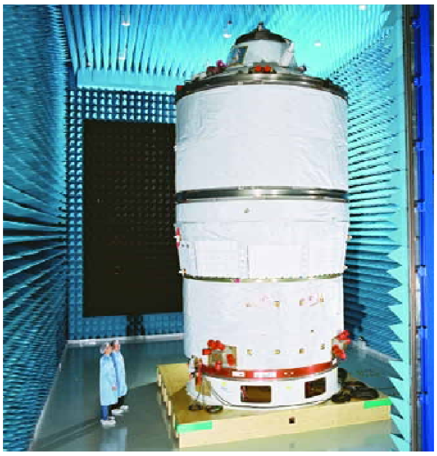
A typical ATV mission begins with launch into a circular orbit atop a new version of Ariane-5 from the French Guiana equatorial site. It is injected into the Station's orbital plane, inclined at 51.6° to the Equator. Under the responsibility of the ATV Control Centre (ATV-CC) in Toulouse (F), it separates from Ariane after 70 minutes and activates its navigation systems,

which fire thrusters to begin its move towards the ISS.

After several days of raising its orbit, ATV comes within sight of the ISS and begins navigating relative to its target, from about 30 km behind and 5 km below. The computers begin final approach manoeuvres over the next two orbits, closing in at a relative speed of a few cm per second while both craft are flying around the Earth at 28 000 km/h.

The approach and docking are fully automatic. If there are any problems, either the ATV computers or the Station crew can trigger one of three programmed anti-collision manoeuvres.

With ATV securely docked, the Station crew enters the cargo section and removes the payload: supplies, science hardware and lightweight bags with fresh food, mail and tapes from their families. Meanwhile, ATV's supply tanks connect to the Station plumbing and discharge their contents. The 100 kg of air for breathing is manually injected by the crew into the ISS atmosphere. For up to 6 months, ATV remains attached mostly dormant, with the hatch open into the Station. The crew gradually fill the cargo section with unwanted equipment and rubbish. Every 10–45 days, ATV fires its thrusters to boost the



Electromagnetic testing at ESTEC in 2005

Station's altitude, which is naturally degraded by the faint but continuous atmospheric drag.

Once its resupply mission is accomplished, and it is filled with discarded items, ATV is closed off by the crew and automatically separates. Its thrusters use their remaining propellants to drop out of orbit – not at a flat angle used for the smooth reentry of manned vehicles, but as steeply as possible for a controlled and safe destructive reentry high above the Pacific Ocean.

From its first operational flight, Europe's most challenging spacecraft will play a vital role in Station servicing. It is also a way for Europe to pay its share in ISS running costs by spending money within European industry rather than by cash transfers to its ISS partners.

The Challenges

ATV is the most versatile spacecraft ever built – it first acts as the upper stage of Ariane-5, then it is a fully independent spacecraft, and, after docking with the Station, it is a supply, life-support and reboost module. Finally, it provides waste-disposal.

Its unique level of autonomy and safety makes it the first fully automated resupply spacecraft of its kind. Even with a malfunction, ATV does not rely on human intervention to ensure mission success and Station safety.

The ATV's design respects a tough requirement: even with any combination of two possible onboard failures, the craft must still be safe for the crew and for the Station itself. It must also tolerate one failure and still complete its mission. This high level of autonomy, courtesy of several layers of safety and failure management, allows ATV to fulfil the entire mission on its own, from navigation in orbit to rendezvous manoeuvres and finally docking with the Station. The whole software package, the most complex ever developed in Europe, has a million lines of code.

ATV's main computer and its three independent sub-computers act as the pilot, controlling the mission. In the event of a major failure during the critical approach phase to the ISS, or if any manoeuvre endangers the Station, a dedicated backup computer will intervene using highly reliable and robust software.

This backup computer isolates ATV's normal system and commands a special 'retrieve' manoeuvre to take the vehicle into a safe trajectory. This independent mode relies on separate computers, separate software, separate batteries, separate trajectory-monitoring sensors, and separate thrusters; only the propellants are shared. This backup system is so segregated from the main ATV systems that it is like a copilot responsible for safety hidden inside the automated spacecraft.

Preparations and Tests

2005 saw small technical problems and failures late in the processing of *Jules Verne*, including a small fatigue failure in a propulsion valve and an anomaly in the drive mechanism of the crucial solar arrays. Together, they snowballed into a launch delay of more than a year.

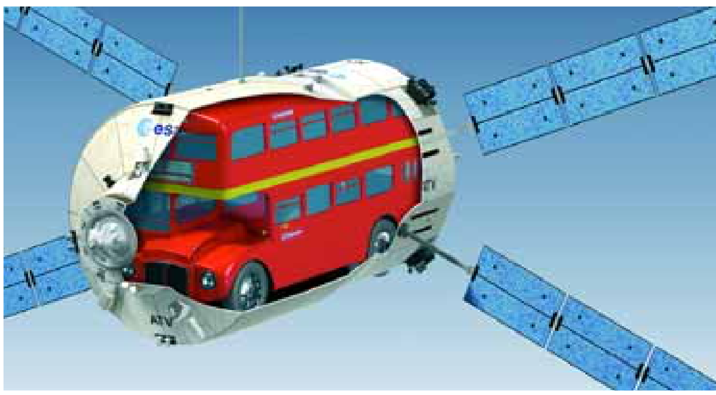
By the end of 2006, the complex environmental test campaign, including the main acoustic and thermal tests, had concluded successfully. In parallel, functional and operations tests were performed at both the ATV-CC in Toulouse and the Functional Simulation Facility (FSF) at EADS-Astrium in Les Mureaux, 50 km west of Paris.

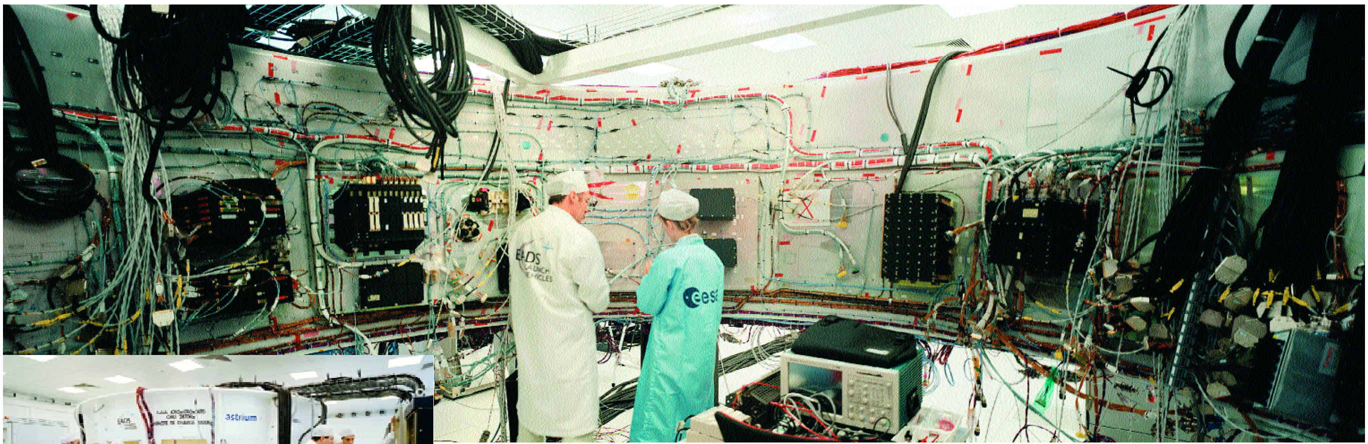
Preparing for acoustic tests at ESTEC

Acoustic and thermal testing

The Large European Acoustic Facility at ESTEC simulated the stress that ATV will encounter during the first 3 minutes of flight atop Ariane-5. The entire ATV structure – the size of a double-decker London bus – must withstand frequencies up to 8 kHz at 143 dB, a level lethal to the human body.

In the second half of 2006, *Jules Verne* completed a series of critical thermal vacuum tests that replicated the harsh





The Functional Simulation Facility in Les Mureaux is replicating the flight of Jules Verne

temperature environment of space. These were the most critical environmental tests for ensuring that all the systems are robust enough to withstand the 6-month orbital mission.

Since early 2006, a primary goal of the *Jules Verne* campaign at ESTEC has been to test the full interaction between the extensive flight software and the real flight hardware of the spacecraft as a whole. Using the Electrical Ground Support Equipment of hundreds of cables and dozens of computers, the flight was replicated.

Similar testing also began early last year at the FSF. This facility housed actual mechanisms from *Jules Verne* and replicas of its electronic 'brain' and 'nervous system' plus ground equipment to simulate all the external interfaces, including up to 60 electronics racks. To be sure that the Facility exactly replicates *Jules Verne*, however, the results from the two campaigns will be closely compared. To make the tests even more realistic, the control centre in Toulouse was added into the loop in early 2007. The preparations and the successful closed-loop simulations with *Jules Verne* took more than 3 months of intense work.

Now that all the numerous tests and campaign challenges are nearing completion, *Jules Verne* should be ready for shipping in summer 2007. The transportation of ATV and its 400 t of support equipment from The Netherlands to French Guiana will take 2 weeks by sea aboard the ship *Toucan*.

Testing the links with the ISS

For the past several months, the challenge has been to run parallel test campaigns in different countries and sites. The primary goal of this complex and time-consuming strategy is to ensure that ATV hardware and software can handle all the possible nominal and off-nominal scenarios that *Jules Verne* might face during its demonstration flight.

For instance, at the RSC Energia plant outside Moscow, home of the ATV docking mechanism, the refuelling system and the complex associated electronics, major computer simulations were underway from December to March. The objective was to test the final version of the software that will link ATV and the Russian Zvezda module during rendezvous and docking. Tests included actual communications hardware and GPS simulators. During ATV's stay at the Station, Zvezda's computers will order the ferry to fire its thrusters to boost the Station's altitude.

At this 'Ground Debugging Complex', a powerful simulator could introduce several failure scenarios and create degraded situations that the ATV architecture had to cope with while respecting the tough safety requirements of human spaceflight.

At the same Moscow plant, a 2-month campaign began in April to test ATV's physical interfaces – the docking system, the complex associated electronics and the refueling system with real fluids and pressurised tanks. *Jules Verne* has the unique capability to refuel the Station with 860 kg of propellants and remove 840 kg of liquid waste.

In summer 2006, thanks to the Europe's largest ship hull test facility at Val de Reuil, west of Paris, it was possible to replicate the rendezvous successfully. For the first time, the system worked under complete closed-loop conditions where all aspects of the spacecraft were either represented for real – software, sensors, trajectories – or simulated, such as thruster firings.

In 2006, ATV's computer and sensors mounted on a mobile platform (left) proved they could approach and dock with the ISS (right) from 250 m out

This rendezvous test campaign brought the different systems together perfectly by using real ATV flight sensors under life-size rendezvous conditions and feeding measurements into the flight control computer. At the same time, a simulator calculated the movements of the vehicle in space. A third system physically translated these computations into a relative motion between the sensors, carried by an industrial robot, and their targets on a huge mobile platform representing the ISS. The integration of all these systems into a closed-loop test worked as planned from some 250 m out all the way to docking.

Astronaut Jean-Francois Clervoy demonstrates the loading of late cargo into ATV

Further information on ATV can be found at www.esa.int/SPECIALS/ATV/

Facing page: ESA's ATV team in Les Mureaux, November 2006. Holding the ATV display photo are Daniel Sacotte (left, Director, HME), Jean-Jacques Dordain (centre, Director General) and John Ellwood (right, ATV Project Manager)

Getting Ready for Operations

Under a contract signed with ESA in 2003, CNES has developed the ATV Control Centre, responsible for monitoring and controlling the vessel during its mission. Since early 2006, dozens of simulations to monitor the *Jules Verne* approach to the Station have required a high degree of technical skill never seen before in European operations.

While attached for up to 6-months, ATV will not only resupply, refuel and boost the ISS, it will also be used to desaturate the Station's control gyros and, if necessary, manoeuvre the complex to avoid space debris.

Several mission scenarios require complex interactions and shared responsibilities between ATV-CC and the Mission Control Centres in Moscow and Houston. For the first time, three space centres around the globe must work together. Special high-level 'Multi-Element Procedures' have been developed, allocating the tasks to be performed sequentially to the centres involved. A dozen simulations involving the three centres are under way to fine-tune the range of possible scenarios, from perfect to degraded missions.

During the flight's highly critical phases, from launch to docking and from departure to reentry, the entire 60-person team in the ATV-CC will work in three adjacent control rooms separated by large glass walls. The main room provides mission execution and management, performed by CNES. In the second room are the flight dynamics engineers. An Engineering Support Team occupies the third, with experts from ESA and EADS-Astrium ready to help in case of a problem.

There is no CapCom (Capsule Communicator) in the ATV-CC but, in case of emergency, the flight director can contact the crew in orbit. The official language during all ATV operations is English, including the communications with Moscow and Houston.

The Extensive Launch Campaign

Since ATV is the heaviest and most challenging spacecraft ever developed in Europe, together with the demanding requirements of manned spacecraft safety, the launch campaign at Kourou will take 3.5 months.

First, in the EPCU S5 (Ensemble de Préparation de Charges Utiles) building, where satellites are prepared for launch, a major leak test will check ATV's 48 m^3 pressurised section and all other pressurised components such as water and gas tanks and the propulsion and the refuelling systems.

Then comes the loading of the dry cargo, in white standard bags of different sizes, stored in the racks of the pressurised section. Most of the 1610 kg of dry cargo carried by *Jules Verne* will be loaded horizontally through the large opening at the aft end of the pressurised module. At this stage, the ATV service module, housing the avionics and the propulsion systems, will not yet be mated to the cargo section. For flexibility, a small fraction of the dry cargo can be loaded through the docking hatch up to 8 days before launch, when the craft is undergoing final preparations on top of the Ariane-5.

The first ATV flight is a demonstration mission, so it will carry a heavier propellant load than subsequent missions. The extra load will allow several scenarios and manoeuvres to be tested, such as retreating into a parking orbit and delaying rendezvous until the following day. The rest of *Jules Verne*'s payload will be 860 kg of refuelling propellants for the Station's own propulsion system, 280 kg of drinking water, 20 kg of oxygen and the 2010 kg of reboost propellants. The extra propellants not consumed for unexpected scenarios during free-flight will be used for additional Station reboosting. All the fluids and gas will be loaded following strict safety rules.

In parallel, the special version of the Ariane-5 will undergo its own launch preparations.

Ariane's Largest Payload

Jules Verne will be launched by a modified version of Ariane-5 known as

the 'Ariane-5 Evolution Storable' (A5 ES-ATV). It comes equipped with the powerful Vulcain-2 main engine and features the storable-propellant upper stage (Etage à Propergols Stockables, EPS) and its reignitable Aestus engine. On subsequent flights, the launcher will inject the 20 750 kg ATV into the ISS orbital plane at around 300 km altitude. For *Jules Verne*, with a mass of 19 400 kg, the circular orbit is at 260 km.

This first ATV is more than double the heaviest single payload ever lifted by Ariane-5. To handle such a heavyweight, the Vehicle Equipment Bay, supporting the ATV atop the launcher, has been significantly strengthened.

The second major change is the modified path taken by the 775 t Ariane-5 during ascent and insertion, allowing for the more severe aerodynamic and thermal demands and the different centre of gravity.

About 3.5 minutes after lift-off, the fairing protecting the ATV is ejected. Five and a half minutes later, the cryogenic main stage (Etage à Propergol Cryogénique, EPC) separates, leaving ATV with its the upper stage. This ATV will reach its initial circular orbit using two burns separated by a 45 minute coast. The first EPS burn lasts about 9 minutes, over the Atlantic Ocean, followed by a ballistic coast half way around the world. Passing over south-east Australia, Aestus reignites for 40 seconds to circularise the orbit at 260 km. Four minutes later, ATV separates over the southwest Pacific and becomes an independent spacecraft. On its own, the EPS reignites an orbit later to deorbit and burn up safely during a precise reentry.

The Launch Date

From April to mid-summer, an extensive review is being conducted with NASA and the Russians to be sure that *Jules Verne*, the facilities and the trilateral procedures are ready to support the inaugural mission.

Whatever happens, the mission will not depart earlier than the second half of 2007. Once *Jules Verne* is ready to go, the launch window depends on several factors such as the angle of the Sun at the time of docking, spacecraft traffic and availability of the ISS aft docking port, Station requirements for cargo and reboost and, finally, Ariane-5 constraints from its own busy commercial manifest.

Finally, all the international partners must agree upon the best date among the possible windows to resupply the Station with up to 6 t of cargo.

The ISS Expedition-16 crew, Yuri Malenchenko (right) and Peggy Whitson (left) began ATV training at the end of February 2007 at the European Astronaut Centre