ATV: Automated Transfer Vehicle

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Some history …

In 1987, at the Den Haag conference, European ministers decided Hermes –a space plane- and MTFF -Man Tended Free Flyer- programmes. But these programmes were abandoned at the next conference in 1992 at Grenada.

In order to maintain exploration programmes, MTFF became Columbus, an ISS module, and Hermes became ATV, Automated Transfer Vehicle.
Main milestones

- **1995**: call for tender issue by ESA
- **1998**: contract signature by ESA–Aerospatiale and after Astrium
- **2002**: Thermal and mechanical tests in ESTEC on the thermal and mechanical mock-up (STM)
- **2004**: First flight model assembly “*Jules Verne*” in Bremen
- **06/2004 – 06/2008**: tests in ESTEC on the flight model and in parallel on the functional mock-up in Les Mureaux
- **30 July 2007**: “*Jules Verne*” arrival in Kourou…
- **9 March 2008**: launch by Ariane 5 ES
- **3 April 2008**: ATV docking to the ISS
- **September 2008**: Separation from ISS on the **5th** and de-orbitation on the **29th**
- **February 2011**: launch of the second model “*Johannes Kepler*”
- **20/21 June 2011**: de-docking from ISS and re-entry of “*Johannes Kepler*”
ATV missions

- Refueling of ISS with propellants
- ISS orbit control
- Debris avoidance
- Gyrodynes / CMG desaturation
- Waste destruction
- Dry payload
- Water and gas
ATV Jules Verne

Mass at Lift Off: 19,357 kg

Dry Mass: 9,784 kg

Total JV Cargo delivered: 4,600 kg (water, Oxygen, dry cargo, fuel)
Famous cousins!

ATV

Apollo

Progress
Large isn’t it!
Integrated Cargo Carrier

Thales Alenia Space (Italie)

Pressurized compartment (46 m³)
- Dry payload: 1150 kg

Russian docking system
(RSC Energy – Russie)

Non pressurized compartment
- Water: 270 kg
- Oxygen: 21 kg
- Propellants: 856 kg

Dry payload: 1150 kg
Spacecraft

Avionic bay (ASTRIUM)

Propulsion bay (ASTRIUM)
- 28 engines 220 N
- 4 engines 490 N
- Propellants (MMH et MON): 5 858 kg (mission and reboost)

Solar array (4 wings – Dutch Space)
- 22 meters span
- 4.8 kW beginning of life
ATV system

Houston control centre

Interconnection Ground Segment COL-CC

Control Centre (CNES - Toulouse)

ISS

Russian Receiving stations

Moscou mission & control centre

TDRSS

ARTEMIS

ProxLink

Via GSFC

TM TC

TM TC

Video

TM TC
Industrial organisation

Prime: Astrium

+ important subcontractors in Russia and in USA
Specificities of the ATV missions

• an Ariane 5 launcher with a re-ignitable upper stage and a dedicated separation system. Station’s orbital plan inclined 51° leading to new tracking stations. Launch on time.

• an autonomous satellite able to « live » in LEO some weeks. It produces energy, regulates the internal temperature, communicates with the station and the Earth.

• a vehicle able to dock autonomously to a man rated space station, which means with a high level of safety.

• when docked, it’s a station module welcoming astronauts, controlling atmosphere and temperature, delivering fluids and equipments.
Main functions of ATV

- Electrical power management,
- Thermal control,
- Vehicle command & control; mission management,
- Station refueling
- Freight management and crew interfaces
- Orbit & attitude control,
- Flight management and collision avoidance,
- Docking and de-docking,
- Station reboost,
- Survival mode management,
System architecture

Three main requirements:

1. The mission must continue with no loss of performances whatever a single failure (Fail Operational = FO)

2. Safety must be guaranteed whatever is the double failure (Fail Safe = FS)

3. Software failure must be taken in account

Organize equipments in 4 avionic chains around 4 1553 communication buses and 4 independent power buses allowing to make redundancy schemes 3 over 4.
Data processing architecture

All the avionics is a centralized system commanded by a fault tolerant computer (FTC). FTC is made of 3 independent digital processing units (DPU) exchanging and voting their inputs and outputs. Inside the 3 DPU’s, is the on-board software in charge of mission and vehicle management, flight control, power and thermal control management and FDIR (Failure Detection, Identification and Recovery). Each DPU is able to control each of the 4 buses with the 80 equipments which are connected to.
Safety

• Safety requirements in the vicinity of the station are insured by a specific sub-system called « Proximity Flight Safety » (PFS). PFS is totally independent and is able to command automatically a Collision Avoidance Maneuver (CAM) on detection of a risky situation, as a collision with the station. A CAM is putting the ATV on an orbit with no intersection with the station orbit guaranteed during the next 24 hours.

• PFS is based on 2 independent computers (MSU) with their own software of high reliability (Class A). The sub-system is powered by an independent source, with separated cells as safety. Two sets of specific nozzles are used for these maneuvers, commanded by specific electronics.
Thermal control main principles

• The avionic bay equipments are dissipating a lot of heat which has to be rejected. But, the ATV is subject to very different sun exposure due to the various attitudes of the ATV and the various sun directions relative to the orbital plane. For the worst hot cases, large radiators are needed.

• But with a classical thermal control, for the worst cold cases, there would be a request for a lot of electrical power to heat the bay. This would lead to unreasonably large solar panels.

An active thermal control system is mandatory

• It is obtained with the use of VCHP: Variable Conductance Heat Pipes. By controlling the conductibility from the equipments to the radiators, the thermal regulation asks for limited electrical power.
Avionic bay

Electrical equipments

Batteries heat pipes

other heat pipes

Radiators for equipments

VCHP evaporator

Tray

Equipment items

Main structure

VCHP condenser

Main radiator

reservoir radiator

NCG reservoir

Equipments supporting structure
Power sources

• 4 cadmium-nickel batteries of 40 Ah each provide energy during orbital night and during some transitory periods as the launch phase, the first orbits, rendez-vous and sometimes during docked mode. The depth of discharge of the batteries is less than 40% without failure and 60% with failure.

• 4 batteries of 33 cells LiMnO2 containing 86Ah are also available for powering equipments linked to safety and to the docking system.
Solar panels

- The solar array is made of 4 independent wings, the rotation of which is controlled. A second degree of freedom is obtained by oscillations in yaw of the overall ATV (during free flight). 0.3 Kg of propellants per orbit is needed.
- The ATV solar array must deliver electrical energy whatever are the shadows made by itself or by the very large panels and the various protuberances of the station.
- The mechanical environment of the station with the vibrations produced by the crew, by the docking of the Progress, Soyuz and the Shuttle, lead to an unusual qualification process of the wings and their rotation mechanisms.
Distribution of solar array panels towards the 4 PCDU (Power Control & Distribution Unit)
Backward view of ATV (reference position of the array)
Jules Verne – Solar array deployment tests
(ESTEC 2005)
Flight control: sensors and actuators

2 star trackers

2 GPS receivers (2 antennas)

2 Videometers

2 Telegoniometers (dedicated to safety)

32 Nozzles

4 Gyrometers (E A B)  
2 axes

3 Accelerometers (EAB)  
2 axes (dedicated to safety during rendez-vous)
Rendez-vous

GPS Navigation

Far range
Rendez-vous

Hyperfrequency link with ISS

GPS relative GPS

5 km -30 km

Far range
Rendez-vous

Ascending transfer towards ISS orbit

Far range

S₀

S₁
Rendez-vous

KURS activation and station lights on

KURS transponder

Far range

-30 km
-15 km
- 3.5 km

S₀
S₁
S₂
Rendez-vous

Transition from far to close range sensors

Far Range

Close Range

Videometers

Telegoniometers
Rendez-vous

Visual Video Target

Russian video system

Crew surveillance

Transition from FAR to CLOSE RANGE sensor

Far Range

Close Range

S₀

S₁

S₃

-30 km

-15 km

-3.5 km

-249 m
Rendez-vous

- Visual Video Target
- Russian video system
- Crew surveillance

Transition from FAR to CLOSE RANGE sensor

Far Range

Close Range

- S₀: -30 km
- S₁: -15 km
- S₂: -3.5 km
- S₃: -249 m
Rendez-vous

Far Range

Close Range

-30 km
S₀

-15 km
S₁

-3.5 km
S₂

-249 m
S₃

-19 m
S₄

Close RVDM
Normal rendez-vous scenario

- Keep-Out Sphere: -250 m
- Station keeping: 5 min
- DUP - DUA distances:
  - -20 m: 2-3 min
  - -12 m: 3-4 min

Approach & Final Approach:
- 21 minutes
- VDM navigation with relative attitude
- Docking port pointing
- Auto-CAM disabling
- GO for final approach

VDM navigation
TGM based monitoring

VDM nav. with rel. attitude
TGM based monit.
Safety of rendez-vous and docking

From the start of the rendez-vous sequence to the final contact, safety is insured by three ways out of the CAM red button:

- **Normal way**: flight control software elaborates propulsion commands from data received from dedicated sensors (raw data GPS, video-meters, star trackers and gyros),

- **Surveillance way**: flight control software utilizes other sensors (accelerometers, tele-goniometers, GPS coherency) and verifies the outputs of the normal way. In particular, it controls that the vehicle is still inside the safety corridors. In case of any anomaly, a stop or an escape or a CAM can be ordered.

- **Abort**: MSU’s, the fully independent computers with specific software, compute a raw position from some sensors and can order a CAM any time and, if such, control the flight during 24 hours.
Russian docking system
(Vladimir Syromiatnikov)
Docking

ATV active docking system

ISS Service Module (Russian)

Passive docking system
Docking
Docking

• Contact
Docking

- Contact

Post Contact

Thrust + Kinetic energy
Docking

- Contact
- ATV Capture
- SM Capture
Docking

- Contact
- ATV Capture
- SM Capture
- Docking start

Breaking activation (30 s)
Docking

- Mast retraction
Docking

- Mast retraction

Roll alignment
Docking

- ATV hooks closing

Aligned interface
Docking

- ATV hooks closed
- ISS hooks closing

Sealed interface

16 min
Docking

- ATV hooks closed
- Hooks closed
- Mast extension
- Catch pins retraction

Mast extension

16 min

(20 s)
Docking

- ATV hooks closed
- ISS hooks closed
- Mast extension
- Catch pins retraction
- Mast final retraction

(80 s)
Final retraction

19 min
Docking

- ATV hooks closed
- ISS hooked closed
- Mast extension
- Catch pins retraction
- Mast final retraction
- ISS hooks locked
Docking

Mechanical docking
Docking

Mechanical docking

Electrical docking

- electrical connections
- data buses connections

Electrical power from ISS
Docking

Mechanical docking

Electrical docking

• electrical connections
• data buses connections

Door opening
50m of European technology
• 25 February 2008: fairing installation
Mission profile: launch
Flight V181 – L528
Sunday 9 March 2008
5h03’04” Paris time

- Re ignitable
- Upper
- stage

Performance:
- 19,357 t
- circular low
- orbit
- altitude 260km
EPS FLIGHT

H3.1 H0+ 17min 10s EPS first burn-out
K2.1 H0+ 9min 47s EPS ignition
H2 H0+ 9min 00s EPC separation
H0+ 3min 29s fairing jettisoning
H0+ 2min 18s EAP separation
H0+ 7s Lift-off
    EAP ignition
H0 Vulcain ignition
Jules Verne re-ignition and separation

- H4.1 H0+ 1h06min 39s ATV separation
- H3.2 H0+ 1h02min 40s EPS second burn-out
- K2.2 H0+ 1h02min 10s EPS Re-ignition
- H3.1 H0+ 17min 10s EPS first burn-out
- K2.1 H0+ 9min 47s EPS ignition
- H2 H0+ 9min 00s EPC separation
- H0+ 3min 29s fairing jettisoning
- H0+ 2min 18s EAP separation
- H0+ 7s Lift-off
  EAP ignition
- H0 Vulcain ignition
Ground tracks of the Jules Verne ATV

SNA: Ariane naval station- SMA: Santa Maria Azores
In orbit first operations

- Communication antennas deployment
- TDRSS link acquisition
- Solar array deployment
- Propulsion system initiation
- GPS system start
- First orbital maneuvers/ demonstrations
Free flight!
• 09th of March – after launcher separation:
  – Communication with the Control Centre
  – Solar array deployment
  – Propulsion, GPS, attitude control activations

• 10th of March – system verification and free flight behaviour analysis
Mission profile

Altitude (km)

Pre-Launch Launch Phasing Rendezvous Attached Phase

Not to scale

Docking – 3.4.2008

S₀, S₁, S₂, S₃, S₄

docking

Hatch opening
ISS re-boost by ATV

25th of April   12th of June   08th of July   06th of August   07th of August
From the Space Shuttle….
profil de mission

<table>
<thead>
<tr>
<th>Altitude (km)</th>
<th>Time</th>
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<tbody>
<tr>
<td>300</td>
<td></td>
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<tr>
<td>400</td>
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<tr>
<td>5.9.2008</td>
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<td>S1, S2, S3</td>
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<td>De-orbit (29.9.2008)</td>
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<td>Re-entry (29.9.2008)</td>
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Re-entrée
Some comments on the second flight, Johannes Kepler:

No failure and no alarm all along the mission

On the 10th of June, the most important re boost of the station was performed. 4.5 tons of propellant used to raise the altitude to 380 Km which is the maximum never reached by the station.

Some beautiful views coming from this flight
Rendez-vous to the next flight in March 2012 with the ATV-3 Edoardo Amaldi