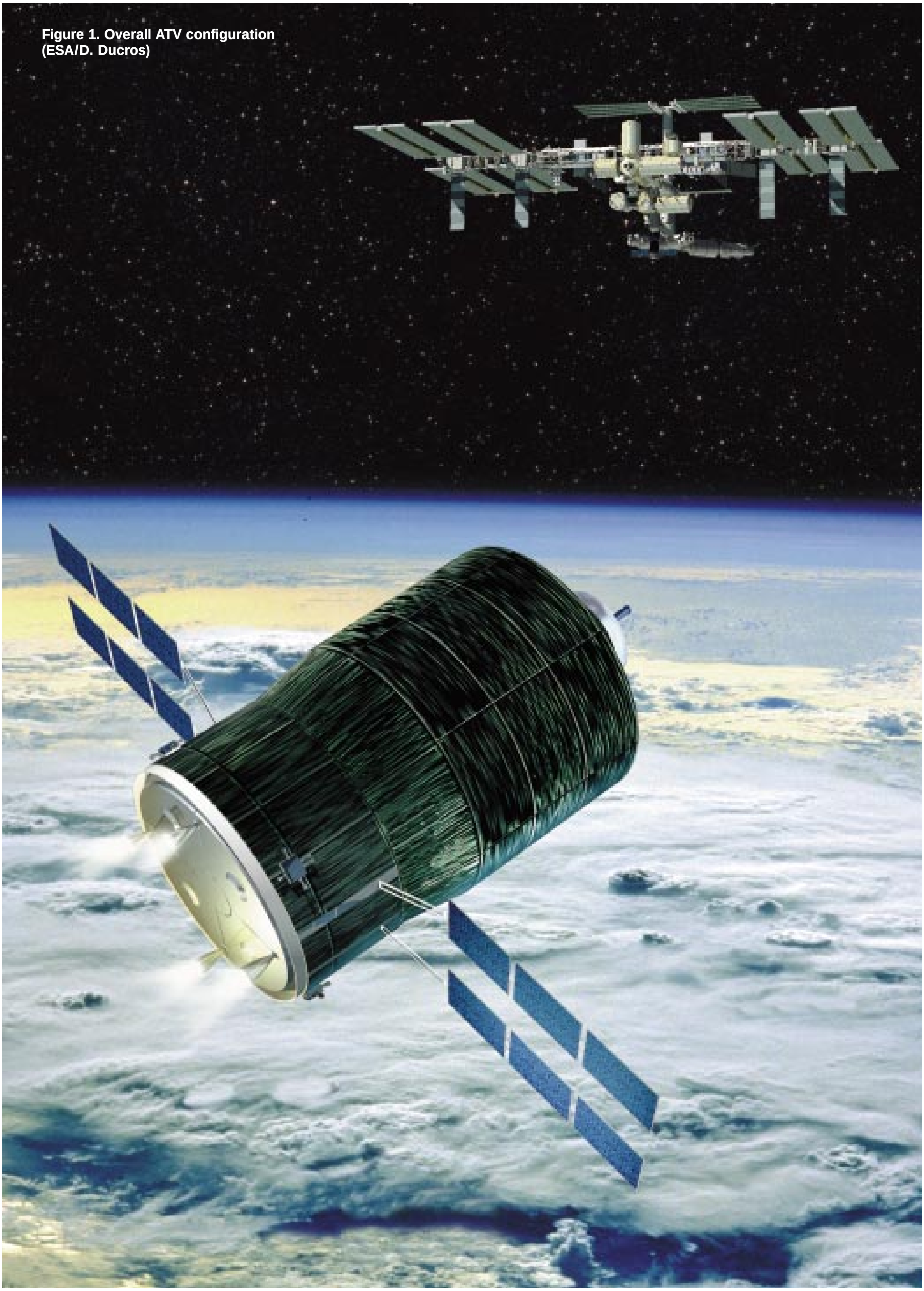

Figure 1. Overall ATV configuration (ESA/D. Ducros)

The Automated Transfer Vehicle

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The development of the Automated Transfer Vehicle (ATV) was confirmed at the October 1995 ESA Ministerial Council meeting in Toulouse by the ESA Member States as part of the programme for European participation in the International Space Station. The ATV will be a servicing and logistics vehicle for periodically resupplying the Station. It will be operational from early 2003, flying servicing missions about eight times until 2013 or more, depending on the Station's lifetime extension. ATV will be the tool to pay in kind for Europe's share of Station common operations costs.

Introduction

As prime contractor for the Automated Transfer Vehicle (ATV) under an ESA contract, Aerospatiale's Les Mureaux establishment is responsible for overall management, system and vehicle engineering; vehicle testing, software development and overall verification of the vehicle and support to the Agency for external interfaces requirements establishment and negotiations.

DaimlerChrysler Aerospace Bremen is the prime contractor for ATV production. The production phase will probably begin in 2000, subject to timely approval by ESA Member States of the International Space Station Exploitation Programme.

Ground processing will take place in Europe and at the launch site in Kourou, French Guiana. Flight operations will be controlled from the ATV Control Centre in Europe during the free-flight phase and taken over by either the Russian Control Centre in Moscow and/or by the Space Station Control Center in Houston when approaching the Station and until docking.

Development status

Since the start of Phase-B2 with Aerospatiale in July 1996, complex negotiations have taken place between ESA and industry on this challenging programme. As a result of several proposal submission cycles supported by a recovery phase in early 1998, an updated Aerospatiale proposal was finally accepted by the ESA Tender Evaluation Board in early June 1998 and the associated contract proposal was approved at the end-June 1998 meeting of ESA's Industrial Policy Committee. Contract negotiations were finalised in July 1998; the contract was signed 25 November 1998.

The mission

ATV will be launched by Ariane-5E (E=Evolution) for the first time in late March 2003. This maiden launch will include specific mission demonstration objectives for final qualification of the ATV mission.

The ATV will provide the following services to the International Space Station:
– Delivery of dry and liquid cargoes to the Station, such as experiments, food, compressed air and water.
– Refuelling of the Station, i.e. the transfer of propellant to the Zarya (FGB) module, built by the Russian company Khrunichev under Boeing contract.
– Reboost and attitude control during reboost of the whole Station, i.e. orbit corrections using the ATV propulsion system to compensate for the continuous loss of altitude by the Station.
– Removal of waste from the Station followed by controlled destructive reentry of the ATV.

Payload capability

The ATV carries, in the same mission, both dry and liquid cargoes. It has an upload capability of up to 7.5 t and a download capability of up to 6.5 t, for a 400 km, 51.6° orbit.

The upload cargo can consist of:
– up to 5500 kg of dry cargo carried in a pressurised environment
– up to 840 kg of water

Figure 2. Docked to the Russian Service Module, the ATV is capable of reboosting the ISS into a higher orbit (ESA/D. Ducros)

Figure 3. Ariane-5 core stage carrying the ATV with the fairing jettisoned (ESA/D. Ducros)

- up to 100 kg of air, oxygen or nitrogen
- up to 860 kg of propellant (306 kg of fuel and 554 kg of oxidiser) for Station refuelling
- up to 4000 kg for reboost and attitude control of the Station.

Mission profile

Ariane-5E injects the ATV into a 30 x 300 km, 51.6° transfer path. The circularisation and phasing operations are performed by the ATV after injection and last about 50 h. At the first apogee, after separation from the launcher, the ATV raises perigee to 400 km to stabilise the orbit. Onboard navigation is initialised by an activation order delivered by Ariane-5E at separation. All ATV operations are monitored from the ATV Control Centre in Europe via NASA's Tracking & Data Relay Satellite (TDRS) system.

Following the perigee-raising manoeuvre, a series of reconfiguration and check-out operations is performed, notably solar array deployment.

A series of phasing manoeuvres is then performed to bring the ATV to the Station altitude of 350-460 km. About 90 min before the ATV enters the approach ellipsoid, integrated operations begin and mission authority is transferred to the Mission Control Center in Houston or in Moscow.

Beginning 30 km from the Station, the ATV performs final approach and docking manoeuvres automatically over a period of 5 h, with either automatic or manual capability from the Station crew to trigger a collision avoidance manoeuvre should any problem occur at ATV or Station level. Upon detection of the first contact between the ATV docking system and the Russian Service Module, the ATV thrusts to ensure its capture and then triggers the automatic sequence of docking operations.

The attached phase lasts up to 6 months. During this phase, the ATV's hatch remains open unless it is closed to minimise the power required from the Station. The crew manually unloads cargo through a pressurised passageway while the ATV is in the dormant mode. Dry cargo of up to 5500 kg is located in a pressurised environment in the secondary structure of the Cargo Carrier. ATV can also carry up to 840 kg of water and up to 100 kg of air, oxygen or nitrogen.

Station refuelling operations are powered and controlled by the Station via specific hardware interfaces in sequence: integrity checks, line venting, fluid transfer and line purging. Propellant tanks in the external module of the Cargo Carrier carry up to 306 kg of fuel and 554 kg of oxidiser. Refuelling may be carried out in several increments.

The ATV is reactivated during the attitude control and reboost operations. These operations can employ the four 490 N thrusters of the main propulsion system, or the twenty 220 N thrusters of the attitude control system.

After departure from the Station, the ATV automatically performs manoeuvres for deorbiting and controlled reentry in the Earth's atmosphere. Carrying up to 5.5 t of waste from the Station, the ATV will be safely consumed during reentry.

Vehicle description

The ATV has a modular architecture. It is composed of the ATV Spacecraft itself and an Integrated Cargo Carrier.

The ATV Spacecraft includes:

– the separation and distancing module that ensures ATV separation from Ariane-5E

Figure 4. The Automated Transfer Vehicle approaching the International Space Station (ESA/D. Ducros)

– the propulsion bay accommodating the Propulsion and Reboost Subsystem
– the avionics bay housing the data management system, the guidance, navigation and control system, communications and thermal control
– the solar arrays.

The Integrated Cargo Carrier accommodates all cargo except for the reboost propellant, which is carried in the Spacecraft. It consists of:

– a cargo carrier with an equipped pressurised module for dry cargoes and an external bay for water and gas tanks and interfaces with the Spacecraft
– the active part of the Russian docking system
– avionics equipment such as rendezvous sensors and proximity link antennas.

ATV subsystems

The Russian Docking System
The Russian Docking System is based on the probe and drogue system used for many years by Russia for docking the Progress and Soyuz vehicles. It provides the ATV with the capture and release functions necessary for docking with and departure from the Station. The system is built in Russia and provided under ESA responsibility through an interagency barter agreement in exchange for ESA providing the Data Management System to the Russian Service Module.

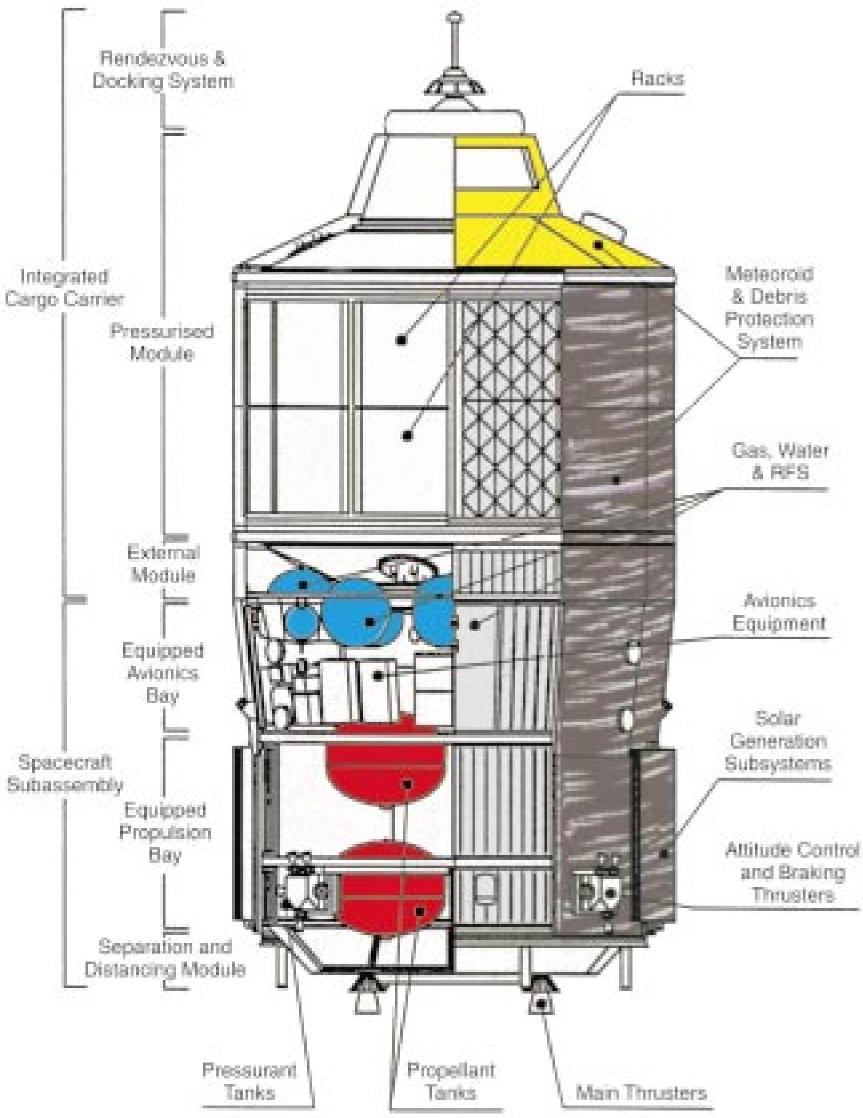

Figure 5. ATV principal elements

Avionics equipment chains
The ATV avionics architecture centres around the Fault Tolerant Computer, composed of four data processing units. These are synchronised, executing functions determined by the software. This software is in charge of overall ATV management during the free-flying phases, from injection by Ariane-5E to ISS docking and from undocking to final destruction at reentry.

Guidance, Navigation and Control
Guidance, Navigation and Control calculations are based on two Global Positioning Satellite (GPS) receivers for position estimation, on four gyros and two Earth sensors for attitude estimation, and on two rendezvous sensors for final approach and docking. The system is in charge of the closed-loop ATV motion control, in particular to bring the vehicle to the specified conditions (position, velocity, attitude and angular rate) for docking with the Station and to the proper position and conditions for reentry to ensure safe debris fall-out.

Communications
Communications with the ATV are provided by two S-band systems: a TDRS link for communications with the ground and a proximity link for communications with the Station. Both systems are completely redundant.

Power generation and storage
The ATV power resources are based on solar arrays and batteries. Four deployable arrays generate power when exposed to the Sun. Rechargeable batteries are used to cover eclipse periods and to directly power the equipment. Non-rechargeable batteries are also used during certain flight phases. During the attached phase, the ATV in dormant mode requires up to about 600 W from the Station. Power is generated, stored, distributed and controlled under the supervision of the ATV mission and vehicle management avionics.

Solar arrays
The solar array subsystem consists of four wings with three panels each. Both gallium arsenide and high-efficiency silicon cells are used. Power at beginning-of-life is up to

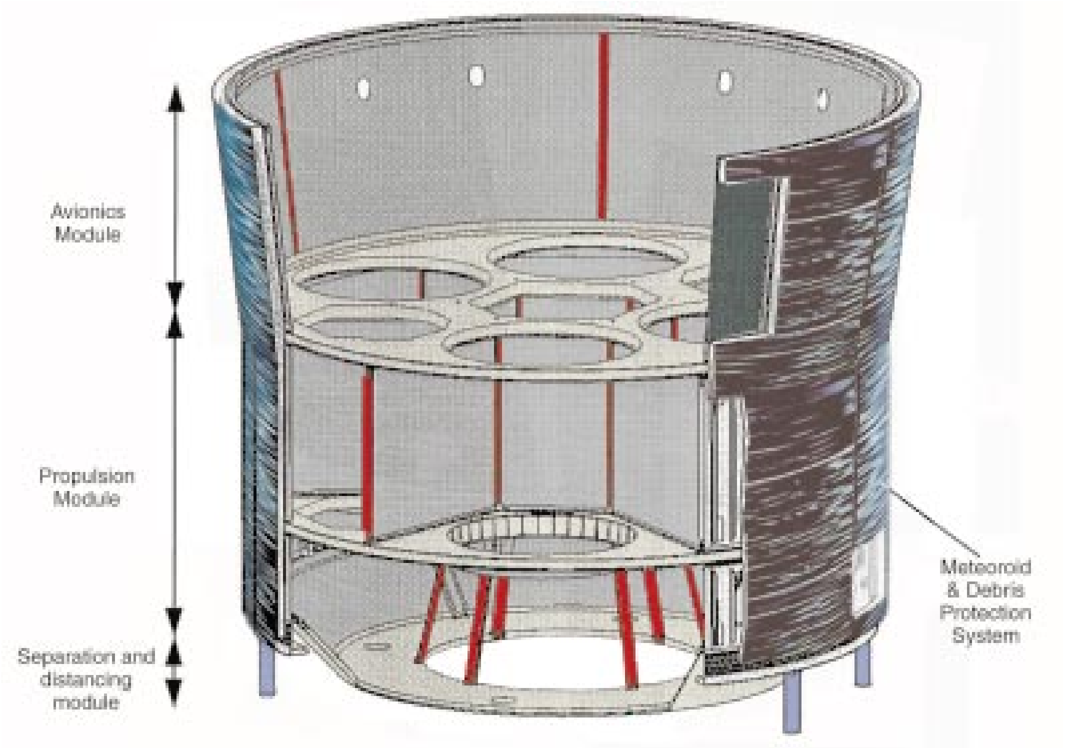

Figure 6. ATV Spacecraft structures

3860 W in Sun-pointing mode; the end-of-life (up to 6 months) output is 3800 W.

Thermal control
The ATV thermal control system is based on a semi-passive concept typical for satellites. Protection against the space environment is provided by multi-layer insulation covering the vehicle. External radiative coatings (aluminised secondary surface mirror coating or absorptive black paint) are optimised locally. Passive radiators and 100 active heaters are also used where necessary, particularly during the attached phase.

Spacecraft structures
Spacecraft structures comprise a Propulsion Module, an Avionics Module, and a Separation and Distancing Module, all of aluminium alloy. They are protected by a Meteoroid and Debris Protection System mounted on the primary structure.

Propulsion and Reboost Subsystem
The bipropellant Propulsion and Reboost Subsystem uses mixed oxides of nitrogen (MON, oxidiser) and monomethyl hydrazine (MMH, fuel) stored in eight identical 1 m-diameter titanium tanks. Tanks are pressurised with helium stored in two high-pressure tanks regulated to 20 bar. Tanks can accommodate up to 6760 kg of propellant for main navigation and reboost requirements. The same tanks are used for ATV propulsion and Station reboost. The system comprises four main engines of 490 N each with a specific impulse of more than 310 s, and 20 attitude control thrusters of 220 N each and a minimum impulse bit of less than 5 Ns.

Major ATV characteristics

The ATV will be launched by the Ariane-5 Evolution version, without the upper storable propellant stage, allowing injection of 20.5 t into a 30x300 km, 51.6° transfer path.
Length: 10.1 m
Maximum diameter: 4.5 m
Span with solar arrays deployed: 18.3 m
Power supply: 3800 W after 6 months
Spacecraft dry mass: 4.6 t
Cargo Carrier dry mass: 3.9 t
Net cargo mass: up to 7.5 t
Total ATV maximum mass at launch: 20.5 t

Industrial organisation
The industrial organisation follows the agreement reached during the October 1995 Ministerial Conference in Toulouse, with Aerospatiale Les Mureaux in charge of development and DaimlerChrysler Aerospace Bremen in charge of production, subject to approval by Europe of the International Space Station Exploitation Programme. An Inter-Prime agreement has been reached between Aerospatiale and DaimlerChrysler Aerospace.

The industrial structure planned for the development phase is as follows:

Aerospatiale in Les Mureaux (France) is the prime contractor for development and is in charge of:
– System engineering
– Vehicle engineering
– Flight software
– Vehicle testing

Alenia Spazio (Italy)
– Cargo Carrier development
– Thermal control studies

DaimlerChrysler Aerospace (Germany)
– Propulsion and Reboost Subsystem
– Spacecraft integration

Matra Marconi Space (France)
– Avionics equipment development
– Avionics Bay integration
– Guidance, Navigation and Control algorithms and software for rendezvous

Oerlikon Contraves (Switzerland)
– Spacecraft structure subsystem
– Dynamic models

Alcatel Bell Telephon (Belgium)
– Electrical Ground Support Equipment

Development plan

The ATV development logic requires three system models: a structural test model, an electrical test model and a protoflight model.

Structural Test Model
– early mechanical tests such as shock and dynamic tests to acquire a better knowledge of the environment and of the structural behaviour of the ATV
– early acoustic tests for validation of equipment's environmental requirements
– structural static tests
– thermal balance tests to validate the thermal mathematical model and the thermal control passive design
– solar generator system deployment test.

Electrical Test Model
– early environmental validation of the avionics subsystem, from the fault-tolerant computer pool and its basic software, up to the whole system by gradually adding the different assemblies and redundancies
– most of the functional qualification of the ATV with the Functional Simulation Facility, which is a ground support element offering simulators for missing equipment (if any), ATV kinematics and simulation of the external environment.

Protoflight Model, for final ATV qualification
– Acoustic tests
– Electromagnetic compatibility tests
– Release tests for the solar generator system
– Thermal balance test
– Complementary functional qualification on the Functional Simulation Facility (hardware and software).

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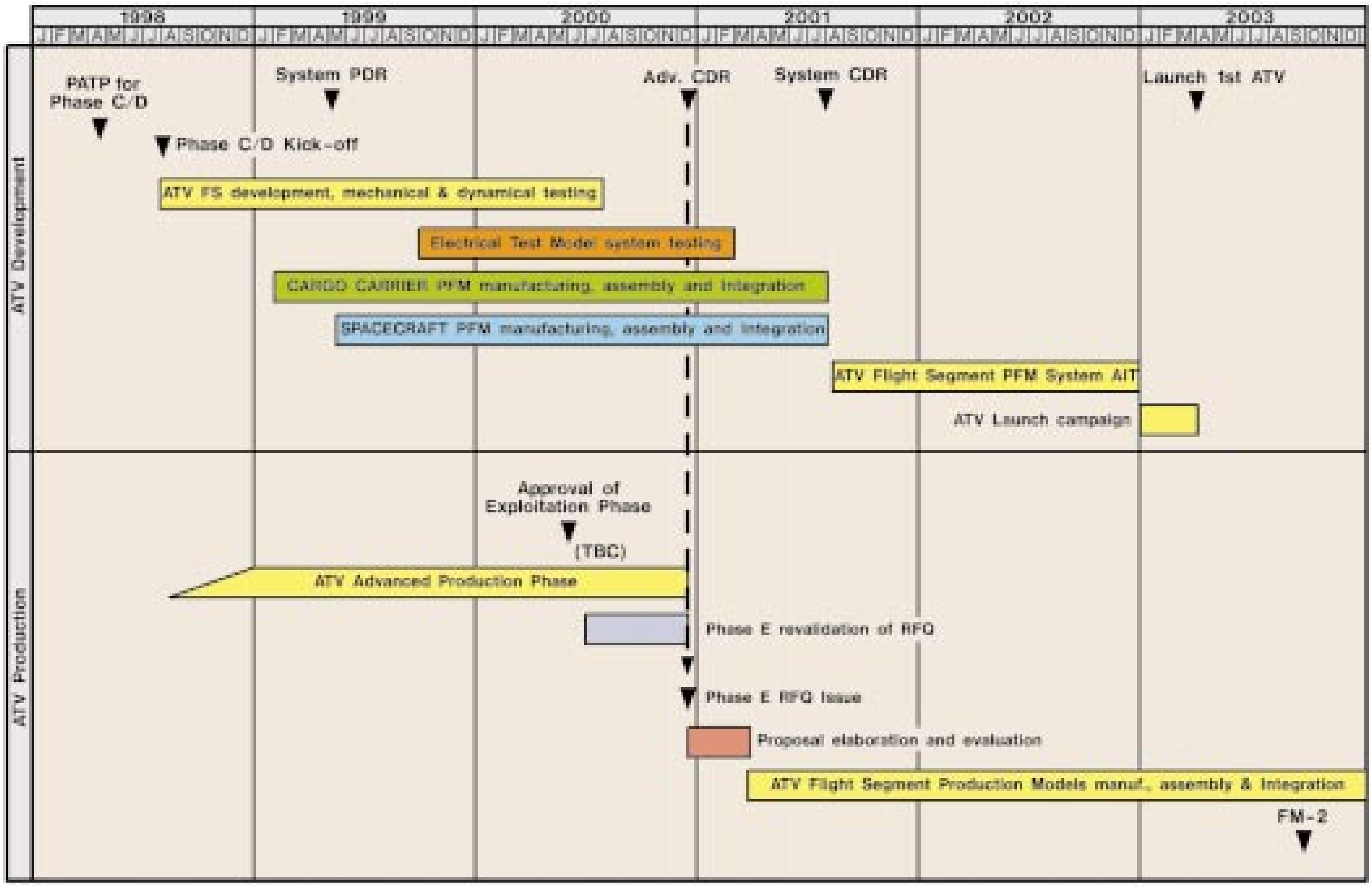

Figure 7. The overall ATV development schedule and transition to the exploitation phase