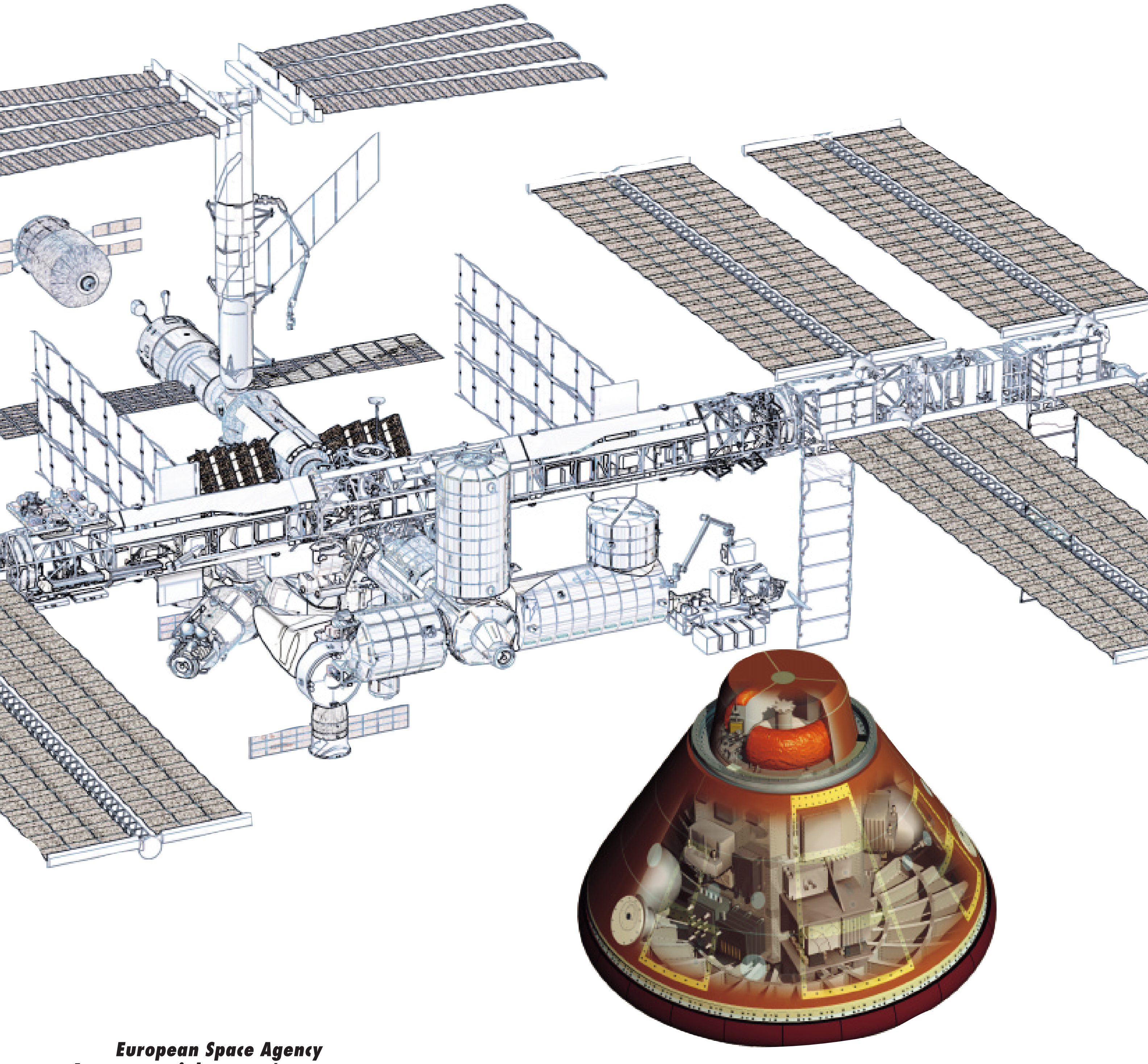
BR-138
October 1998

The Atmospheric Reentry Demonstrator



European Space Agency
Agence spatiale européenne

Directorate of Manned Spaceflight and Microgravity
Direction des Vols Habités et de la Microgravité

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What is the Atmospheric Reentry Demonstrator?

ESA's Atmospheric Reentry Demonstrator (ARD) is a major step towards developing and operating space transportation vehicles that can return to Earth, whether carrying payloads or people. For the first time, Europe will fly a complete space mission – launching a vehicle into space and recovering it safely.

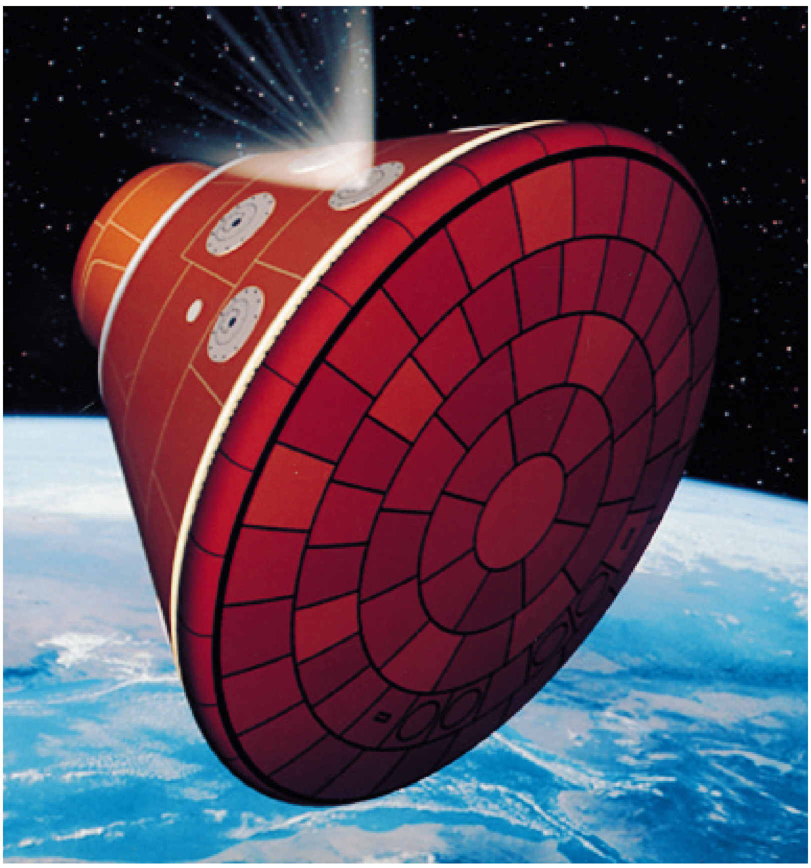
The ARD is an unmanned, 3-axis stabilised automatic capsule that will be launched on top of an Ariane-5 from the European space port at the Guiana Space Centre in Kourou, French Guiana. Its suborbital ballistic path will take it to a maximum altitude of 830 km before bringing it back into the atmosphere at 27 000 km/h. Atmospheric friction and a series of parachutes will slow it down for a relatively soft landing in the Pacific Ocean, some 100 min after launch and three-quarters of the way around the world from its Kourou starting point.

The ARD is a heavily-instrumented test vehicle. During the flight, it will record and transmit to the ground more than 200 critical parameters for analysis of the flight and the behaviour of the onboard equipment. It is also planned to locate the capsule after splashdown and, if possible, to retrieve it for return to Europe and a more detailed technical analysis.

What are the objectives of the ARD?

The ARD will allow Europe to study the physical environment to which future space transportation systems will be exposed when they reenter the Earth's atmosphere. It will test and qualify reentry technologies and flight control algorithms under actual flight conditions.

In particular, the ARD has the following main demonstration objectives:
- validation of theoretical aerothermodynamic predictions,
- qualification of the design of the thermal protection system and of thermal protection materials,
- assessment of navigation, guidance and control system performances.



Seven thrusters will orient the ARD during atmospheric entry.

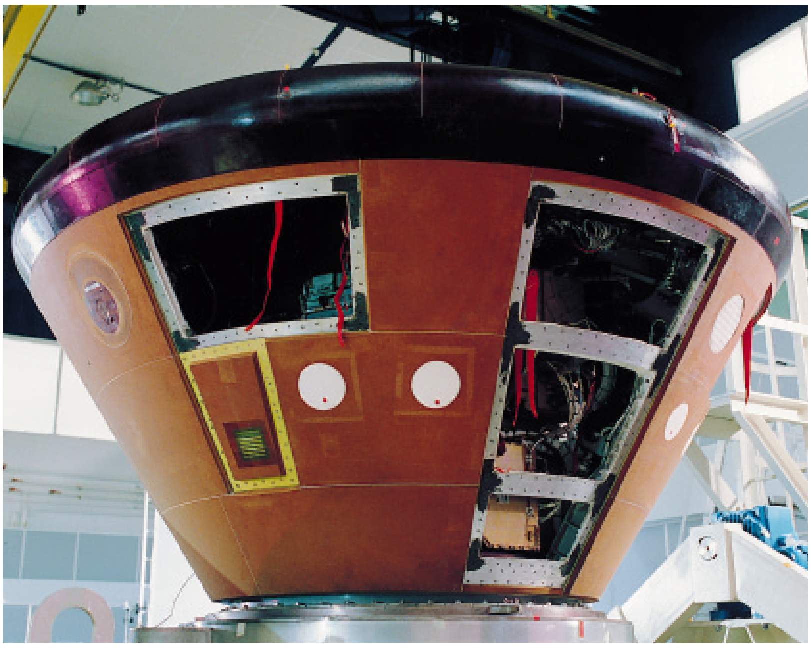
Further objectives are:
– the assessment of the parachute and recovery system,
– the study of radio communications during atmospheric reentry.

As a pilot project, the ARD is demonstrating that Europe can develop a complete space vehicle in a shorter time and with a smaller budget than in the past. Last, but not least, the ARD is also a historic flight for Europe.

Why is this flight historic?

So far, Europe has built satellites for all possible scientific, governmental and commercial applications, and carried them into space on its Ariane launchers. It has also developed and operated automatic platforms (Eureca, Spas) and a manned laboratory (Spacelab). However, it relies on other partners to carry these elements into space, deploy and retrieve them, and to return them safely to Earth. To date, only the US and Russia have fully

Artist's impression of the assembly of the ARD on Ariane-5's Speltra in Kourou.



mastered the technical and operational know-how for both the ascent and return phases of space vehicles.

With the flight of the ARD, Europe is undertaking a complete spaceflight cycle, from launch to landing, with its own expertise for the first time.

Why is the ARD important for Europe?

Flight through the Earth's atmosphere imposes an enormous stress on a space vehicle. This is true in both directions: during ascent after launch, and during reentry at the end of the mission. The speeds associated with spaceflight are very high: at least 27 000 km/h is necessary to achieve low Earth orbit. Space vehicles suffer considerable buffeting and heating from the aerodynamic friction created by such high speeds. Without the appropriate aerodynamic shape, robust mechanical structures, heat-resistant materials and intelligent automatic flight control systems, the vehicle would simply break up and burn under the harsh conditions.

Reentry technology is not only important for space vehicles returning to Earth from space, but also for space transportation vehicles that carry payloads into space. These vehicles, or at least their lower stages in the case of a multi-stage vehicle, generally fall back towards Earth after completing their transport missions. The Ariane-5 core stage reenters the atmosphere at almost the same speed as a vehicle returning from low Earth orbit. Mastering reentry technology is not only important for guiding the upper stages of expendable launch vehicles into safe trajectories back to Earth, but it will be even more important for the development of future space transportation systems.

Ariane-5 and other advanced space transportation systems have reached the limits of what is achievable today using classical mechanical and power designs. Further improvements in payload-carrying capability, accompanied by a significant reduction in launch costs, require a real quantum leap in the technical and operational approach: instead of discarding the launch vehicle, or at least important parts of it, after each launch, it will be recovered whole for reuse on further missions.

This will not be easy. The road to reusable space transportation systems will be difficult, but if Europe is to maintain the remarkable position it has achieved with the Ariane launcher family, and if it intends to take up the challenges of the future launcher market, it has to master the reentry technologies that will play an increasingly important role in the launch vehicles that are expected to come after Ariane-5.

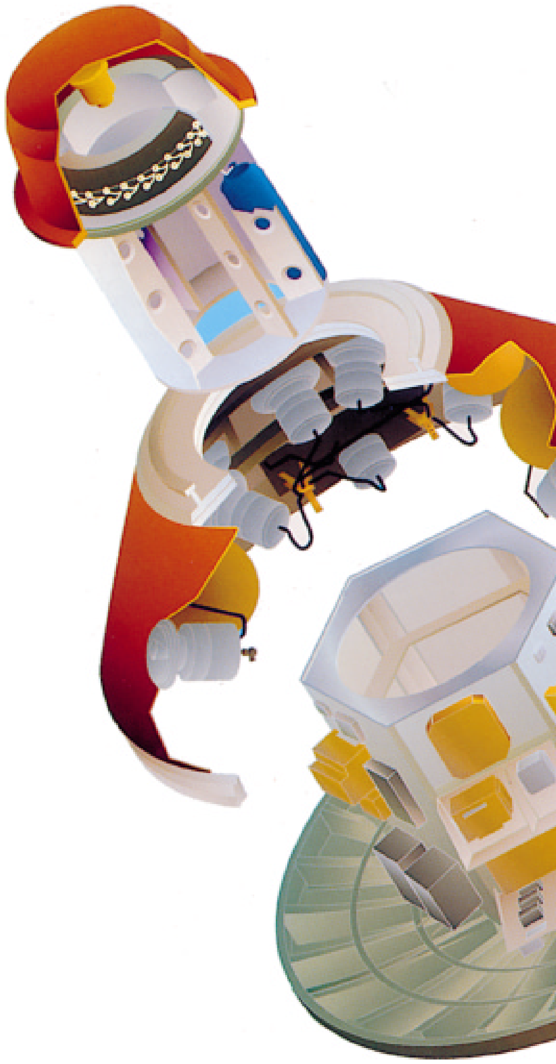
Acquiring its own competence in these key technologies is also important if Europe wants to become an appreciated and respected partner in the possible governmental and industrial cooperation structures of the future for the development of such vehicles.

The Atmospheric Reentry Demonstrator is an important step for Europe in achieving these strategic goals.

What is the overall design of the ARD?

The ARD has an external diameter of 2.80 m, an overall height of 2.04 m and a launch mass of 2800 kg. Roughly speaking, it looks like a 70%-scale Apollo capsule, with the remarkable difference that it incorporates modern technologies.

The ARD has an air- and water-tight pressurised structure. In principle, it is designed to float by itself. However, after landing, two balloons will make sure that it floats upright, with the heatshield fully immersed in the water. This position contributes to better thermal equilibrium and ensures that the Sarsat (satellite search and rescue) radio beacon and flashing light that guide the recovery ship are not immersed.



The ARD comprises four main elements:

- a bulkhead structure that carries the heatshield,

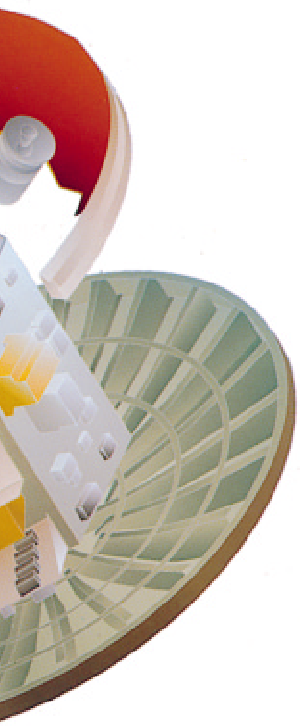
- a conical section that incorporates the reaction control system and houses an internal secondary structure,
- a secondary structure inside the conical part to support the electrical equipment,
- a back cover to protect the descent and recovery systems during flight.

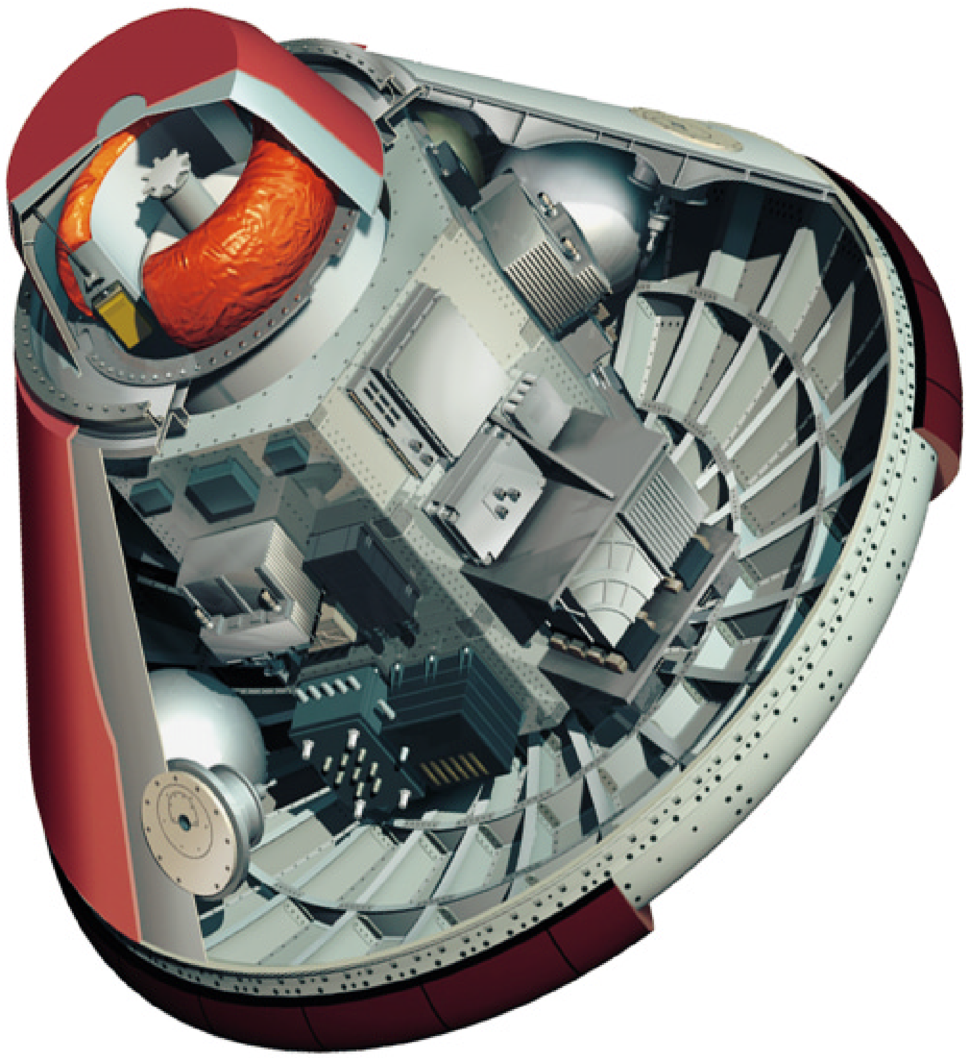
All structural elements are made of mechanical-fastened aluminium alloy parts. The outer surface of the ARD is covered with heat-protection material of different types.

What are the main system functions of the ARD?

Aerodynamics and automatic flight control

ARD's flight can be divided into three phases: ascent into orbit as a payload of





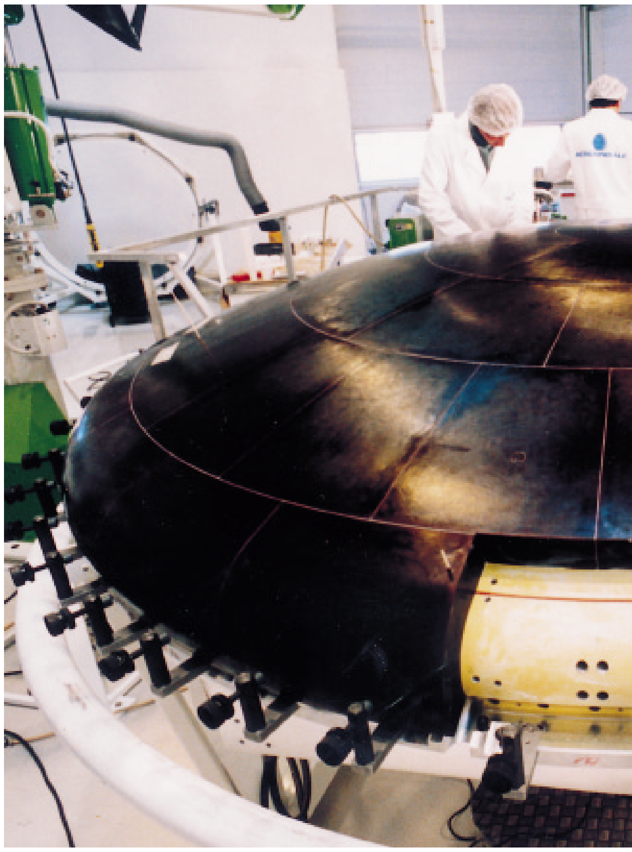
ARD vehicle architecture.

Ariane-5; a free ballistic flight through space; and an aerodynamic, automatically guided flight through the atmosphere.

As soon as it reenters the atmosphere, the ARD will become an aerodynamic vehicle that automatically controls its flight path with the help of the onboard navigation, guidance and attitude control system. It will be like an aircraft in autopilot mode, with the substantial difference, however, that the ARD will be travelling at hypersonic speed and, in place of control surfaces such as ailerons, elevators and rudders, it will use small rocket thrusters to change flight attitude.

To save time and money by avoiding the need for a long aerothermodynamic selection process, an existing aerodynamic shape was adopted. The dimensions and masses were defined based on Ariane-5's performance capabilities and on ballistic reentry parameters that could be representative for a later Crew Transport Vehicle. As a result, the ARD is a spheroidal-conical capsule very similar in shape to a NASA Apollo capsule and, roughly speaking, a 50%-scale model of what could be an operational transportation vehicle capable of reentry.

The ARD's automatic navigation, guidance and control system consists of a Global Positioning System (GPS) receiver, an inertial navigation system, a computer, the associated data bus and power supply and distribution system, and a reaction control system. The reaction control system is derived from Ariane-5's attitude control system, using seven 400 N thrusters drawing on hydrazine (N_2H_4) carried in two 58-litre tanks



pressurised by nitrogen. The thrusters are positioned so that three provide control in pitch, two in roll and two in yaw.

One of ARD's objectives is to validate the flight control algorithms that were developed as part of the former Hermes spaceplane programme. The guidance algorithm is similar to that used by NASA's Space Shuttle, based on a reference deceleration profile and also used by Apollo. This approach allows a good final guidance accuracy with limited real-time calculation complexity and storage requirements. The accuracy is expected to be 5 km, equivalent to kicking a goal with a football from a distance of 25 km. ESA's initial requirement for landing precision was 'better than 100 km'.

ARD's conical surface is coated with thermal protection consisting mainly of cork powder and phenolic resin.

In order to reach the target and to hold deceleration levels to 3.5 *g* and thermal flux within acceptable limits throughout the whole flight, the ARD will snake to the left and right of the direct flight path with the help of the reaction control system thrusters.

ARD's controlled reentry phase will last about 15 minutes. The position and velocity information required for the automatic control system will be calculated during flight from the accelerations measured by inertial navigation system. During reentry, the ARD will also activate a GPS receiver which is expected to indicate its position and velocity with great precision. However, the GPS data will be added into the control loop algorithms only if they appear to be inside a 'credibility window' defined by classical inertial navigation.

The GPS data will also be used to augment the post-flight analysis of the actual flight path. In fact, the performance of the automatic system depends on the quality of the guidance

Thermal protection tiles are applied to the ARD heatshield at Aerospatiale.

algorithms and the accuracy of the velocity and position data. Comparison with the GPS information will distinguish between the dispersions arising from the inertial navigation systems and those generated by the guidance function itself.

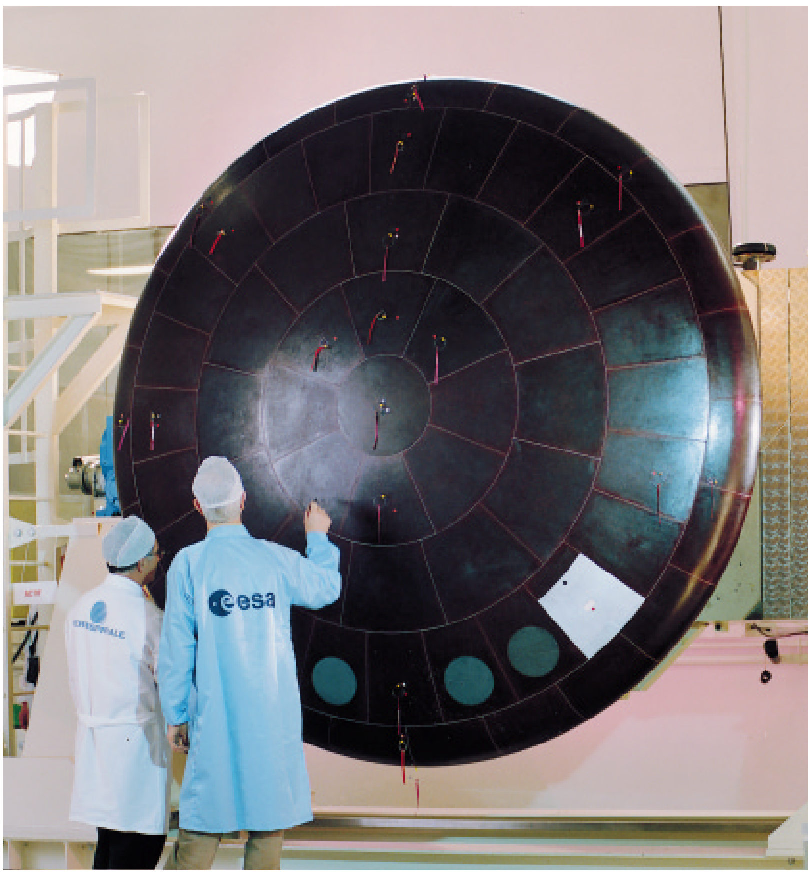
It is worth noting that, although GPS navigation has become a mass consumption product today, the applications where the user travels at more than 27 000 km/h are few indeed.

Thermal protection
During reentry into the atmosphere, ARD's heatshield will be exposed to temperatures ranging up to 2000°C and a heat flux as high as 1000 kW/m², resulting from the ionisation of the surrounding atmosphere under the aerodynamic pressure of the hypersonic vehicle. On ARD's conical area, the temperatures could reach 1000°C, with a heat flux of 90-125 kW/m². Inside, the temperature will not rise above 40°C.

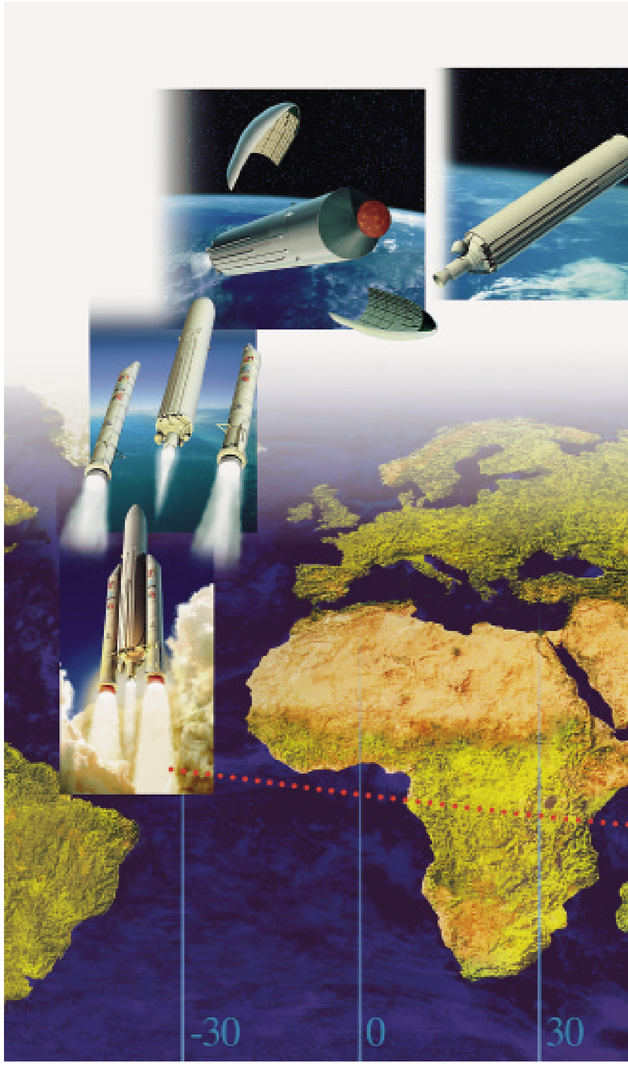
Most of ARD's thermal protection elements are based on materials already developed by Aerospatiale within French strategic defence programmes. However, the flight will also test a number of new-generation materials.

The 600 kg heatshield is composed of 93 tiles made of Aleastrasil, a compound containing randomly oriented silica fibres impregnated with phenolic resin. These tiles are arranged as one central tile and six circumferential rings. ARD's conical surface is coated with Norcoat 622-50FI, composed mainly of cork powder and phenolic resin. In addition to these 'classical' materials, six samples of new materials are included: four Ceramic Matrix Composite (CMC) tiles on the heat shield, and two flexible external insulation panels on the conical surface. The Aleastrasil material has a very low ablation factor: it is expected that the

ARD's heat shield includes four Ceramic Matrix Composite test samples; three are visible here.



Principal stages in the mission of ARD



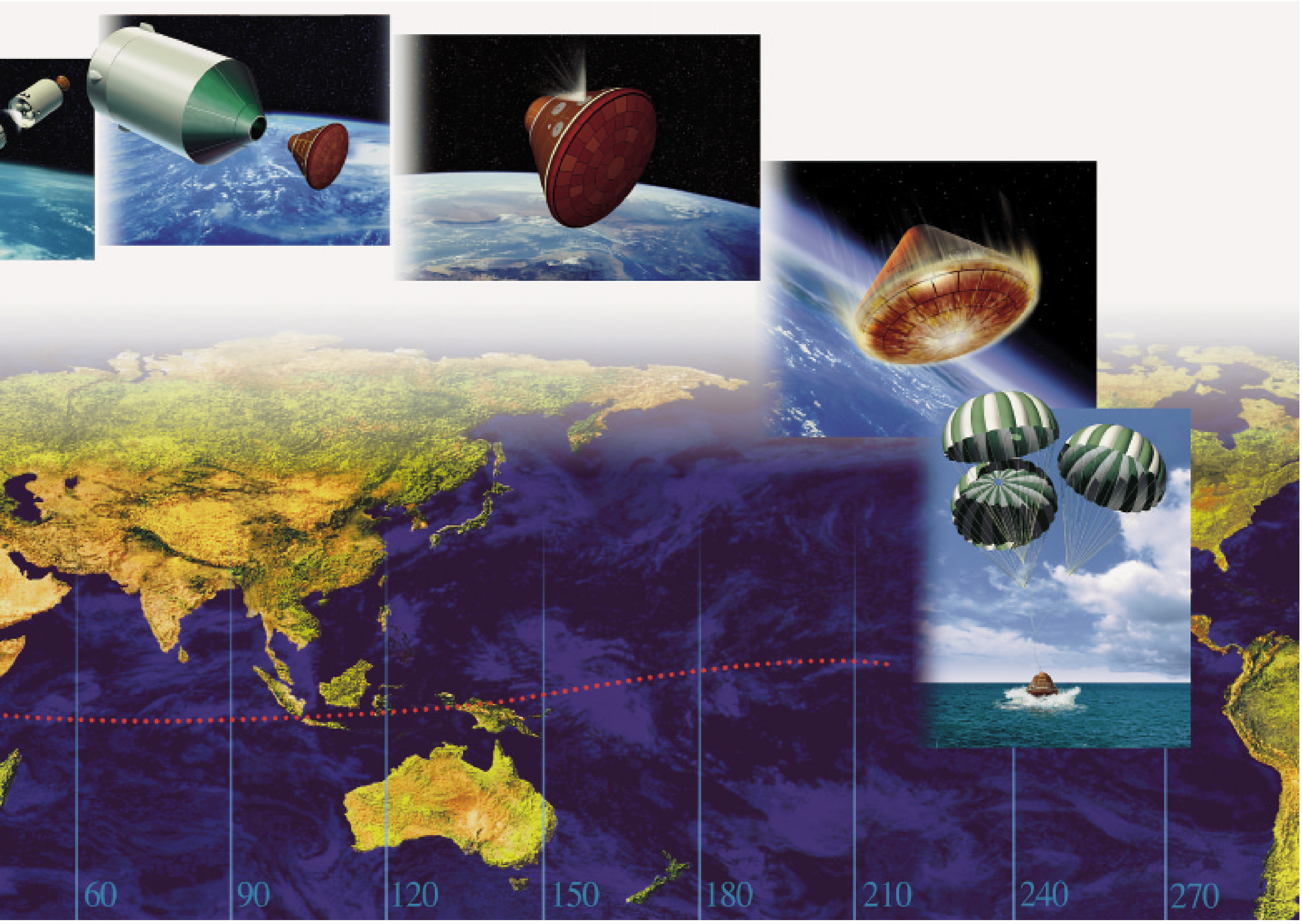
heatshield will lose only 0.5 mm of its thickness during reentry. This has the advantage that ARD's aerodynamic shape can be considered as constant, which considerably helps the flight control algorithms.

Descent and recovery
The descent and recovery system is designed to decelerate ARD before splashdown in order to limit the impact loads and to ensure flotation for up to 36 h. The system consists of a mortar for ejecting the first extracting parachute, several staged parachutes, two balloons to ensure upright flotation, and a Sarsat radio beacon to transmit ARD's position through a satellite system to the ARD Mission Control Centre in Toulouse. The ARD is also equipped with a flashing light to guide the recovery boat. That vessel can also directly receive ARD's Sarsat radio beacon.

In order to avoid tearing the parachutes, the deployment sequence will not begin until the speed falls below Mach 0.8, probably around 14 km above the Pacific, depending on the actual atmospheric conditions (pressure, temperature, humidity) in the landing zone. Maximum dynamic pressure as the sequence begins is 5500 Pa.

The 0.9 m-diameter extraction parachute is ejected by a mortar from under the back cover on the ARD's conical part. This small parachute then extracts a 5.8 m-diameter drogue parachute, typically at an altitude of 13.5 km. The drogue is partially folded ('reefed') to reduce its air resistance and unfolds to its full diameter in two steps. That is jettisoned 78 s later at 6.0 km altitude, and a set of three 22.9 m-diameter main parachutes is released. They are also reefed and open fully in three steps in order to avoid over-stressing the system. They will slow the descent rate to 6.8 m/s (20 km/h). After landing, these parachutes are separated and the two balloons inflate to ensure upright flotation. The descent and landing system has been qualified at real-scale during a dedicated balloon drop test over the Mediterranean Sea.

Onboard measurement and telemetry
Since the ARD is primarily a technology demonstrator, it is important to obtain as much information as possible from the flight on the aerothermodynamic reentry environment, the behaviour of the thermal protection materials, the performance of the navigation, guidance and control hardware and software, and



the functioning of the parachute and recovery system.

Consequently, more than 200 different parameters will be measured and recorded during flight and transmitted to the ground at up to 250 kbit/s. The onboard measurement scheme covers 121 temperature channels, 38 pressure channels, 14 accelerometer and gyro channels, 8 reflectometer channels, 5 force measurement channels, 1 acoustic channel and a number of functional parameters such as mission sequences.

The temperature measurements will record the temperature history within the classical and the new-technology thermal protection materials on the heatshield and the side cone, within the structure and in the reaction control system thrusters. They will be used mainly for qualifying the thermal protection material, but will also evaluate aerothermodynamic heat fluxes.

The pressure measurements will be made on the outer surface (heatshield and conical section). Together with the associated temperature measurements and the reflectometer measurements, they will validate the aerothermodynamic predictions on heat flux and pressure distributions.

The accelerations and rotations measured with the help of the inertial navigation system and additional accelerometers will be used to reconstitute the flight trajectory, to identify the ARD's

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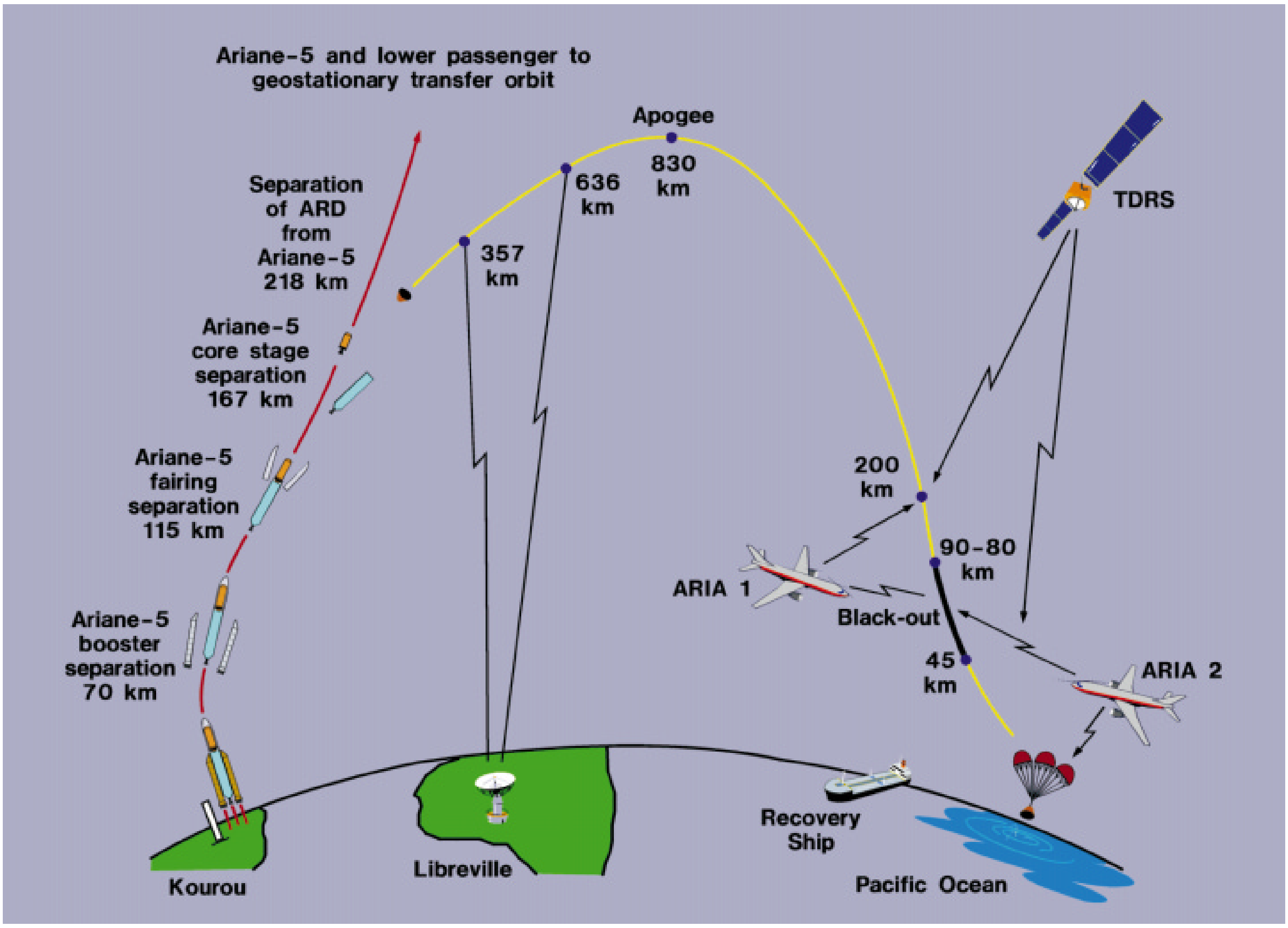
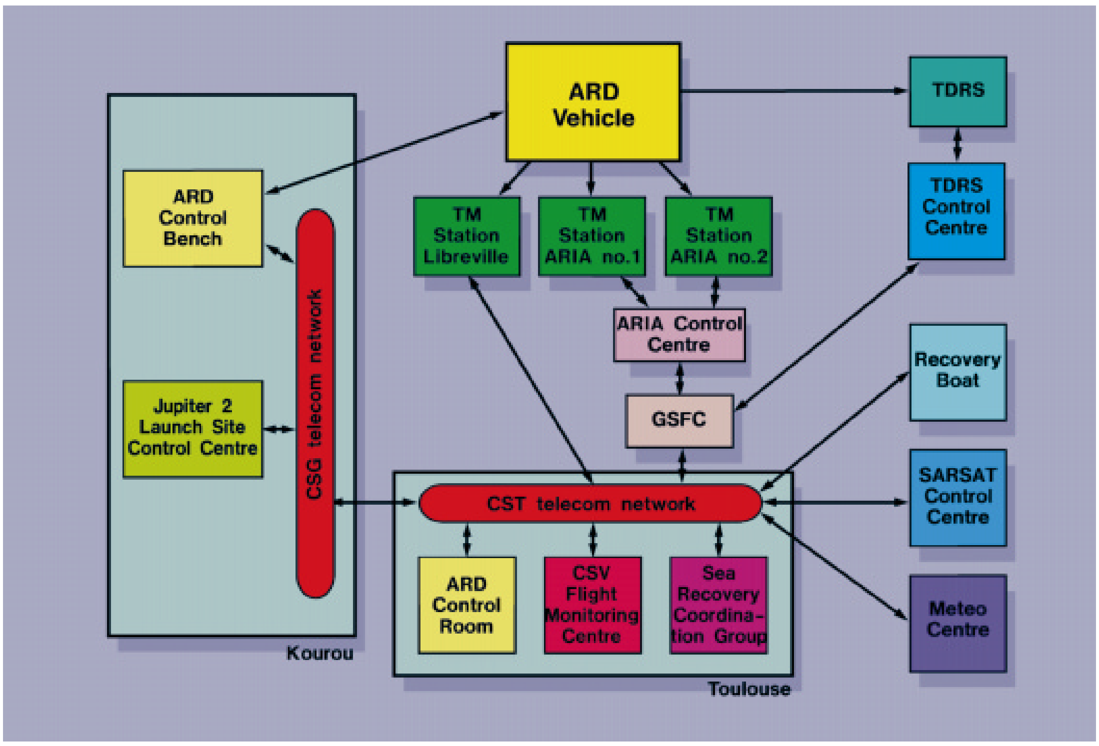


Ariane-5 and lower passenger to geostationary transfer orbit
Apogee
830 km
636 km
357 km
Separation of ARD from Ariane-5 218 km
Ariane-5 core stage separation 167 km
Ariane-5 fairing separation 115 km
Ariane-5 booster separation 70 km
TDRS
200 km
90-80 km
ARIA 1
Black-out
45 km
ARIA 2
Recovery Ship
Kourou
Libreville
Pacific Ocean



ARD Vehicle
TDRS
TDRS Control Centre
ARD Control Bench
CSG telecom network
TM Station Libreville
TM Station ARIA no.1
TM Station ARIA no.2
ARIA Control Centre
GSFC
Recovery Boat
Jupiter 2 Launch Site Control Centre
CST telecom network
SARSAT Control Centre
ARD Control Room
CSV Flight Monitoring Centre
Sea Recovery Coordination Group
Meteo Centre
Kourou
Toulouse

What is the ARD flight sequence?

The ARD will be mounted on the top position of Ariane-5's SPELTRA multiple payload carrier structure, with the heatshield pointing in the direction of flight .

L_0: the flight begins with the liftoff of Ariane-5 from Kourou's ELA-3 launch complex.

L_0+2 min 21 s: altitude 70 km, Ariane's two solid-propellant boosters separate from the core stage.

L_0+3 min 13 s: altitude 115 km, Ariane's fairing, which shields the payload from aerodynamic pressure during flight through the dense layers of the atmosphere, separates.

L_0+9 min 59 s: altitude 167 km, Ariane's core stage shuts down and separates from the upper stage which continues to carry the SPELTRA, the ARD and the second Ariane-5 payload. The following phase is an unpowered ballistic flight (the upper stage fires only after releasing the ARD).

L_0+12 min 2 s: altitude 218 km, in a manoeuvre called 'largage en route' ('release on the fly'), Ariane's upper stage releases the ARD into a ballistic suborbital trajectory. The upper stage, together with the SPELTRA and the second payload, continues its flight into a geostationary transfer orbit.

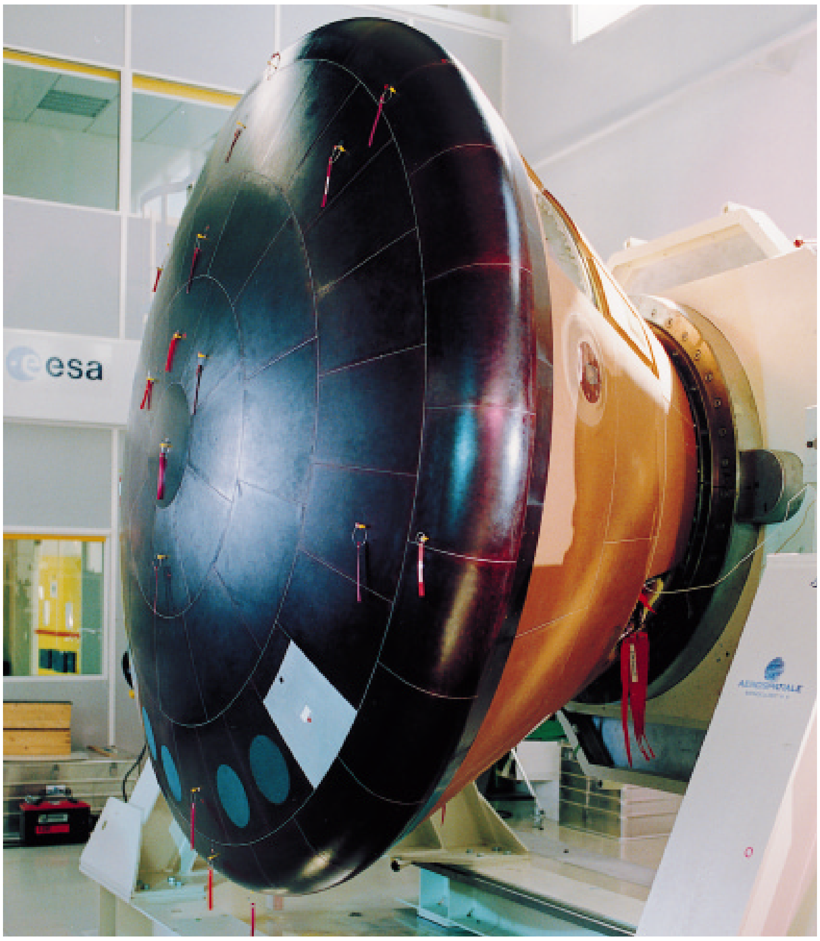
L_0+12 min 30 s: the ARD begins automatic flight control. Between altitudes of 357 km and 636 km, the ARD will be within radio visibility of the Ariane ground station in Libreville, Gabon, which will forward the telemetry to the ARD Control Centre in Toulouse. The Centre will only monitor the flight and receive telemetry, and will not send any commands to the ARD.

L_0+43 min 21 s: the ballistic arc culminates at an apogee of 830 km above the Indian Ocean over 78.50°E/5.40°S, south-east of the Maldives Islands and north-east of the British island of Tchagos. When the ARD has descended to about 200 km altitude, telemetry will be received by the first ARIA aircraft. It will also be in contact with a TDRS satellite.

L_0+78 min: altitude 120 km, above the Pacific Ocean, speed 7533 m/s (27 130 km/h), the ARD enters the atmosphere on a trajectory angled 3° below the horizontal. This marks the beginning of the aerodynamic flight phase. In order to reach the landing zone with 5 km accuracy and to keep the deceleration forces and thermal fluxes within authorised limits, the ARD automatically curves either side of its nominal flight path using its thrusters. At 90 km altitude, the heating begins to become significant. At 90-80 km altitude, the ARD is expected to enter the radio blackout zone; at 45 km, it emerges from the blackout. The second ARIA aircraft is positioned to receive telemetry from the moment the ARD ends blackout until it lands on the water.

L_0+88 min 12 s: speed about 800 km/h (Mach 0.8), at an altitude of 14 km (the actual values depend on the atmospheric conditions) the automatic parachute deployment sequence begins with the ejection of the small extraction parachute. The drogue parachute is deployed 500 m lower down. 78 s later, at an altitude of 6 km, the three main parachutes are released for a splashdown of <20 km/h.

L_0+100 min: the ARD lands at 134.0°W/3.9°N, south-east of Hawaii and north-east of the French Marquesa Islands. Two balloons inflate for stability. The analysis of the telemetry received and relayed to Toulouse by the second ARIA aircraft and the signals of the ARD Sarsat beacon will allow the capsule's location to be determined within 1500 m. The recovery ship will stand off at a safe distance to avoid being hit by the ARD or its debris in case the guidance system fails and the capsule breaks apart under the thermal and dynamic stresses. Having received the landing coordinates from the ARD Control Centre, the ship will approach within 100 m. It will then wait for 10 h before venturing any closer. During this time, the water will cool the capsule so that there is no risk of an explosion from the hydrazine remaining in the attitude control system. A recovery team of divers and technical specialists will then secure the ARD in the water and lift it on board the ship. The vessel will deliver it to Papeete (Tahiti) in French Polynesia, from where it will be transported by a commercial ship to Europe and returned to prime contractor Aerospatiale in Saint-Médard-en-Jalles near Bordeaux in France for inspection and testing.



ARD integrated at Aerospatiale, Bordeaux.

aerodynamic coefficients and to evaluate the dynamic stability and robustness of the automatic guidance and control system. The information from the Global Positioning System (GPS) receiver will be used in the post-flight analysis of the flight behaviour.

Some technology measurements will be made on the parachute system, including monitoring all deployment phases with a video camera, a tri-axial accelerometer, and a number of strain gauges on main parachute lines.

One mission objective is to study communications possibilities during reentry and, in particular, to make a detailed analysis of blackout phenomena and their effect on radio links. Radio blackout is expected between 90 km and 40 km altitude owing to the ionisation of the super-heated atmosphere around the vehicle from dynamic compression. As soon as the ARD descends to 200 km it will be in telemetry contact with two US Air Force aircraft. At the same time, the ARD will be transmitting to NASA's Tracking & Data Relay Satellite (TDRS) system and will receive signals from GPS satellites. The attenuation and blackout phenomena affecting the aircraft, TDRS and GPS links will be carefully analysed after the flight. This should help to suggest ways of countering the phenomena. This was possible with the US Space Shuttle, which manages to maintain TDRS contact despite the ionisation of the surrounding atmosphere However, the Shuttle reenters at only 2-3 *g*, compared with the ARD's 3-3.5 *g*.

Does the ARD use technologies from other programmes?

Maximum use was made of existing technology and off-the shelf hardware in order to keep the ARD's development schedule short and the development cost low.

The attitude control system is derived from the Ariane-5 system. The electrical system, the telemetry hardware, the test-rigs and some of the software also come from Ariane-5. The pyrotechnic gear, the thermal protection and the antennas stem from French defence programmes. The batteries are similar to those aboard Spot 4. The GPS receiver is derived from that carried by France's Rafale fighter aircraft. Most of the know-how on hypersonic aerodynamics, advanced heat protection systems and hypersonic flight algorithms derive from the former Hermes spaceplane programme.

Preparing to launch the ARD test model on a stratospheric balloon from Trapani, Italy to demonstrate the descent and recovery system. Inset: the same capsule was later used for a recovery test and training session off Tahiti.

How many ARD models have been built?

In line with the climate of 'faster, cheaper, better', the classical approach of building a flight model and a number of models of various degrees of fidelity for geometrical, electrical and other ground engineering tests was abandoned in favour of producing the single 'protoflight model'. This means, however, that an additional ARD flight model cannot easily be built by upgrading existing ground models to flight standards.

Has there been any test flight before the ARD's flight on Ariane-5?

In addition to the protoflight model, a test model for qualifying the parachute and recovery system under actual flight conditions was built. This model was carried by a stratospheric balloon to an altitude of 23 km. The capsule was released and fell to 14.7 km, where the parachute sequence was automatically initiated at a dynamic pressure of 5336 Pa (specification: 5500-5000 Pa) and a speed of Mach 0.75 (specification: M<0.8). The capsule landed safely on water with an impact velocity of <6.8 m/s and was recovered by boat. The whole descent phase lasted 924 s. The drop test was performed under the industrial responsibility of Alenia, which made use of the services of the stratospheric balloon launch base of the Italian space agency (ASI) in Trapani, Sicily.

The same drop test model was later used for a water recovery test and training session in the Pacific Ocean by a French military recovery ship.

What ground facilities will be used?

The ARD will be launched from the Guiana Space Centre in Kourou, French Guiana. It will make use of the centre's usual ground preparation and control facilities.

During the ballistic flight phase, ARD's telemetry will be received by a ground station in Libreville, Gabon, belonging to the Guiana Space Centre network. That station will be within radio visibility when the capsule is between altitudes of 357 km and 636 km.

This test model demonstrated the descent and recovery system in July 1996 after being released from a high-altitude balloon launched from Trapani, Italy.

During the reentry phase, as soon as the ARD has descended to about 200 km altitude, it will transmit radio signals to a NASA TDRS satellite and to one of the two Advanced Range Instrumentation Aircraft (ARIA) waiting in the reentry zone.

The ARIAs are special KC-135 aircraft equipped for receiving telemetry data from reentry vehicles. They are very similar in design to the Boeing B-707. They are operated by the US Air Force and leased by ESA through NASA. Normally based at Edwards Air Force Base in California, they will operate for the ARD mission out of Hawaii. One ARIA will position itself to receive the telemetry before the ARD enters radio communication blackout, while the second will wait for it to emerge.

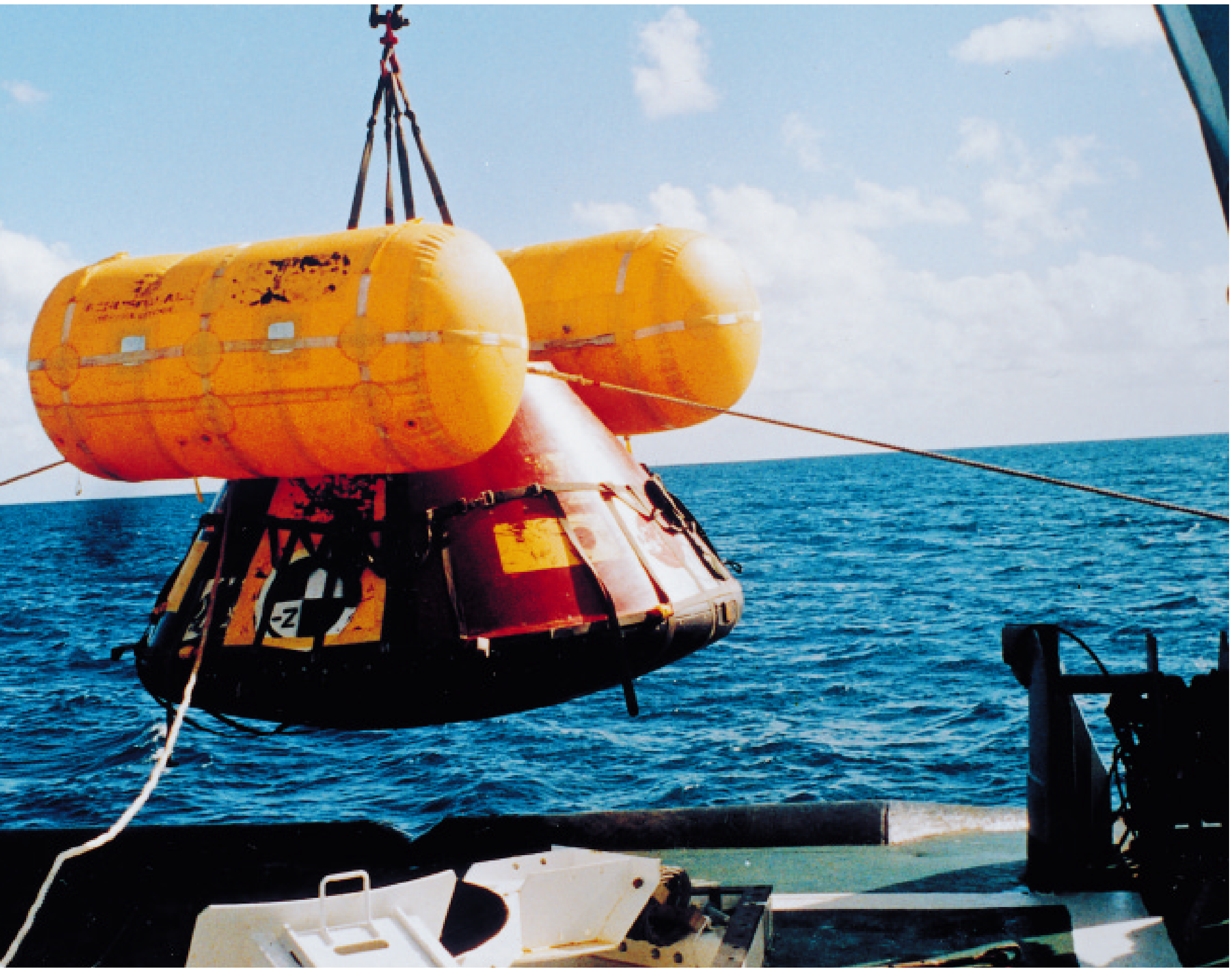
The information received by them will be forwarded from the ARIA control centre to NASA's Goddard Space Flight Center near Washington DC, which will relay them, together with the information received through the TDRS control centre, to the ARD control centre in Europe.

The ARD control centre is located within the Toulouse Space Centre of the French space agency (CNES). It consists of the ARD control room, the flight monitoring centre and the sea recovery coordination group, and will maintain close contact with the Sarsat control centre, the meteorological centre and the recovery ship in the Pacific Ocean.

The recovery ship is a type RR 4000 tug and supply vessel of the French Navy, equipped for receiving ARD telemetry. It will wait for the ARD near the Equator, south-east of Hawaii and north of the French Marquesa Islands. It will also launch balloons to profile the atmosphere at the landing site. If the sea recovery is successful, the ARD will be returned to Aerospatiale in Bordeaux for further analysis.

What if the ARD cannot be recovered at sea?

Should the parachute and recovery system fail or the sea recovery be unsuccessful, the mission will still be considered as a success provided that the telemetry transmitted during descent yields extensive knowledge of the flight conditions and the behaviour and performance of the flight control systems and thermal protection materials.



What if the ARD guidance system fails?

The flight parameters have been chosen so that, even in the event of a total malfunction of the ARD, the capsule will descend safely in the Pacific Ocean, far from any human settlement or maritime route. As it will be injected by Ariane-5 into a suborbital ballistic trajectory, the ARD cannot go into an orbit around the Earth. Even with no further action by its automatic guidance system, it would only describe a three-quarter circle around the Earth and then fall back into the Pacific Ocean, very much like the core stage of Ariane-5 itself. However, without the proper orientation of its heatshield by the attitude control system and the limiting of the deceleration forces by active flight manoeuvres, the ARD would not reach its landing target with a precision of 5 km and there would be the risk of it breaking apart and its pieces beginning to melt before hitting the water. That is why the recovery ship will wait at a safe distance until splashdown. This also means that television pictures of the landing will not be possible.

Is sea-landing an option for future operational reentry vehicles?

Finding and recovering a relatively small object floating in the sea is an extremely difficult and risky undertaking. This has been demonstrated by early US space programmes and, more generally, by the extensive experience with shipping accidents and military aircraft crews who come down over water.

What is the total ARD cost?

The fixed-price contract with Aerospatiale for the development of the ARD was valued at ECU 30 million. The modifications resulting from the Ariane-5 failure led to additional expenditures of ECU 3.2 million.

The atmospheric drop-test cost ECU 1.8 million. The ARD ground segment represents a value of ECU 4 million. Additional ECU 4 million are reserved for the detailed analysis and evaluation of the results from the ARD flight, a task requiring about 1 year.

In total, the whole ARD project, covering the flight segment, the ground segment, the evaluation of the flight, as well as additional activities, will cost about ECU 43 million.

It is very difficult to locate an object in an unstructured, moving environment, without any landmark or other visual clue. For the recovery itself, the main problem is that, if the landing on the water takes place far from the coast, helicopters cannot reach the landing zone and fixed-winged aircraft cannot land on the water.

It is therefore mandatory to pre-position one or more ships in the target area. Additional ships are required in order to allow for an accidental landing outside of the nominal area. In the case of a manned vehicle, it is important to reach the landing point rapidly, since the crew cannot tolerate rough seas for very long. The Apollo programme showed that such recovery operations require considerable naval forces.

Securing the vehicle in the water and lifting it aboard a recovery ship under all possible weather conditions is an additional challenge. It requires experienced and courageous specialists who often put their lives at risk.

Water landing is therefore chosen only if the otherwise preferred landing on solid ground is not feasible because of technical or safety reasons.

For the ARD, a water landing was selected because, as a prototype vehicle, it is not certified to reenter the atmosphere and land over populated areas.

What are the applications and future evolution of the ARD?

The ability to reenter safely, fly through the atmosphere and perform a precision landing is the prerequisite for the development of any space vehicle that returns to the ground, be it an unmanned launch vehicle or a manned spacecraft.

The experience gained with the ARD will therefore benefit Europe's future launcher programmes after Ariane-5, such as FESTIP (Future European Space Transportation Investigation Programme), and the cooperation with NASA on the X-38 programme. The X-38 is an experimental vehicle designed to validate the technologies for a Crew Return Vehicle for the International Space Station, capable of carrying astronauts back to Earth in an emergency. The European share in the X-38 is primarily concentrating on aerodynamics, hot structures and fuselage structure, control surface systems, landing gear and other essential hardware and software items.

In a broader sense, there are also synergetic effects of the ARD with scientific research vehicles that are able to enter the atmosphere of other planets or moons. For example, ESA's Huygens Probe, delivered by the Cassini Orbiter, will land on Titan, Saturn's largest moon, in 2004. The Huygens entry vehicle was developed and manufactured by the same industrial prime contractor as the ARD: Aerospatiale in Bordeaux.

Which industrial companies have been involved?

Under the lead of Aerospatiale's Space and Defense Division, located at Saint-Médard-en-Jalles near Bordeaux, France, 27 European and US companies participated in the realisation of the ARD. The major contractors and their areas of technical responsibility are:

- Aerospatiale (France) as prime contractor was responsible for vehicle layout; thermal protection; architecture and validation of the guidance and navigation system; onboard and ground segment software; assembly, integration and testing; antennas.
- Alenia (Italy) together with Irvin in Italy and USA was responsible for the descent and landing system, i.e. the parachute system and the flotation equipment, including the balloon drop-test in Trapani (Sicily). Alenia was also in charge of thermal control and participated in the in-flight measurements.
- Daimler-Benz Aerospace (Germany) was responsible for the reaction control system.
- ETCA (Belgium) developed the functional control bench.
- Matra Marconi Space (France) was responsible for the functional electronics.
- SABCA and SONACA in Belgium developed the structure.
- TRASYS (Belgium) was involved in software development.

Further subcontracts involved Sextant Avionique, Intertechnique and Onera in France, ABT and ETCA in Belgium, Saab in Sweden, Alcatel in Denmark and Crisa in Spain.

The industrial set-up resulted in a work share of approximately 50% of the total contract value of ECU 30 million for French companies, 20% for companies in Belgium, 15% in Germany and 15% in Italy.

About 200 people across Europe were involved in the development of the ARD.

Is the ARD Europe's response to the call for 'Better, Faster, Cheaper'?

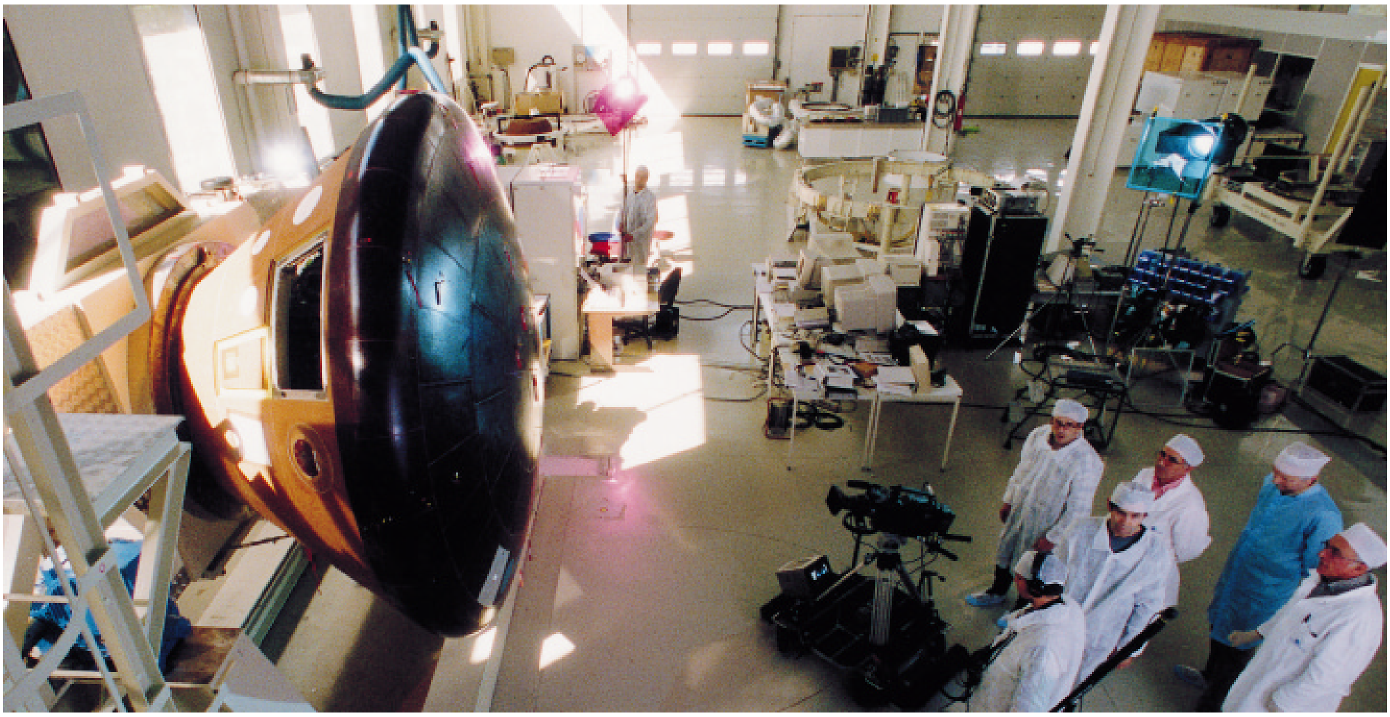
The ARD was not only seen by the European Space Agency as a technology demonstrator, but also as a management demonstrator to show that Europe can take up the challenge of 'Better, Faster, Cheaper'. Its development was thus contracted by ESA to Aerospatiale as a fixed-price contract, with less rigid technical requirements and a larger freedom for the selection of subcontractors than usual in the past.

Aerospatiale had already gained a substantial knowledge of reentry technology through its involvement in the former ESA/CNES Hermes spaceplane programme and in French strategic missile programmes. Furthermore, in order to keep development time short and development cost low, Aerospatiale was requested to make use of existing and flight-qualified equipment wherever possible.

On the Agency side, a lean in-house management structure was adopted, delegating as much responsibility as possible to industry. A joint project team was set up in Toulouse, composed of ESA and CNES engineers who had already worked on the Hermes spaceplane programme and its follow-up programme, the Manned Space Transportation Programme.

This approach resulted in a record-breaking development time of only 24 months, within a budget envelope of roughly ECU 11 000/kg for ARD flight hardware. Comparable satellite programmes have traditionally required substantially longer development times using budgets typically within ECU 100 000-1 000 000/kg for flight hardware.

It is also worth noting that the kilogramme price of the ARD is even lower than the transportation cost of the launch vehicle itself. (Ariane-5 costs about ECU 20 000/kg transported into orbit).



What are the milestones of the ARD project?

The Procurement Proposal for the ARD was submitted to the Industrial Policy Committee of ESA in January 1994. The 3-month Feasibility Study was completed in April 1994. It was followed by a 5-month Preliminary Design Phase for which the formal contractual kick-off with Aerospatiale took place on 6 July 1994. This phase was completed by a Preliminary Design Review in September 1994.

The Development Contract with Aerospatiale was signed on 30 September 1994. A Detailed Design Phase started immediately and was completed by a Critical Design Review in March 1995.

The development of equipment and elements lasted until December 1995. Integration and testing took place between November 1995 and September 1996.

Unfortunately, the failure of the first Ariane-5 flight in June 1996 not only produced a substantial delay of the second Ariane-5, for which the ARD was originally planned, but also the decision to launch the capsule with its particular launch and separation sequence ('largage en route') only on the third Ariane-5. Consequently, the ARD was placed in storage at Aerospatiale.

The findings of the Ariane-5 failure commission led to a number of ARD modifications, since the capsule had adopted existing Ariane-5 hardware, in particular the inertial navigation system. With the changes made, the Qualification Review of the ARD was successfully conducted in March 1997.

The drop test from a stratospheric balloon took place in Trapani (Sicily) on 14 July 1996.

After the formal reconfirmation of the ARD on the third Ariane-5 flight, and the definition of the launch campaign schedule for this flight, the Final Acceptance Review for the ARD was conducted at Aerospatiale in Saint-Médard-en-Jalles on 11 May 1998. The following day, the ARD was officially handed over to ESA and then shipped to Kourou, where it arrived on 15 June 1998, ready for the launch campaign.

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