# Ariane-5

*Achievements:* first European heavy-lift satellite launcher; 9 launches by Mar 2001; planned launches 5 in 2001, 6 in 2002, 6 in 2003, 8 in 2004
*Launch dates:* debut Ar-501 4 Jun 1996 (failed); first success Ar-502 30 Oct 1997; first operational flight Ar-504 10 Dec 1999; debut Ar-5ESV planned 2002; debut Ar-5ECA planned 2002; debut Ar-5ECB planned 2005
*Launch site:* ELA-3 complex; Kourou, French Guiana
*Launch mass:* 746 t (Ar-5G), 767 t (Ar-5ESV), 777 t (Ar-5ECA), 790 t (Ar-5ECB)
*Length:* depending on fairing configuration 46.27-53.93 m (Ar-5G), 46.27-53.43 m (Ar-5ESV), 50.56-57.72 m (Ar-5ECA), 51.51-58.67 (Ar-5ECB)
*Performance:* optimised for geostationary transfer orbit (GTO); see separate table
*Principal contractor:* EADS Launch Vehicles (industrial architect)

The ESA Ministerial Council meeting in The Hague, The Netherlands in November 1987 approved development of the first European heavy-lift launch vehicle. Although Ariane-1 to -4 proved to be remarkably successful, it was clear that a new, larger vehicle was required to handle the ever-growing sizes of commercial telecommunications satellites. The goal was to offer 60% additional GTO capacity for only 90% the cost of an Ariane-44L, equivalent to reducing the cost/kg by 44%.

At the time of approval, it was intended that Ariane-5 would also be tailored to carry the Hermes manned spaceplane. Although Hermes was later shelved, the design can still be man-rated if required. The standard 'lower composite' of stage-1 plus boosters is aiming for a reliability of 99%, an order of magnitude greater than for Ariane-4. Ariane-5's overall reliability target is 98.5%. Like Ariane-4, it is optimised for dual-satellite launches into GTO.

ESA is responsible (as design authority) for Ariane development work, owning all the assets produced. It entrusts technical direction and financial management to CNES, which writes the programme specifications and places the industrial contracts on its behalf. EADS Launch Vehicles (the former Aerospatiale) acts as industrial architect. ESA/CNES were directly responsible for the first three launches, before Arianespace assumed responsibility for commercial operations. The new vehicle is expected to completely replace Ariane-4 in 2003.

Kourou's ELA-3 and associated processing areas were constructed as dedicated Ariane-5 facilities to permit up to 10 launches annually (8 is the current target). Unlike Ariane-4, the payload assembly is integrated with the vehicle before they are transported to the pad only 8 h before launch, in order to minimise pad operations. A launch campaign covers 21 days; the payload is mated 6 days before launch. The simplified pad concept deletes the requirement for large cryogenic arms on the umbilical tower by feeding the propellants from below the mobile launch table. It also reduces vulnerability to launch accidents. There are four principal buildings in the preparation zone:

- Bâtiment d'Intégration Propulseur (BIP) integration hall for the solid-propellant boosters to be assembled and checked out;
- Bâtiment d'Intégration Lanceur (BIL) launcher integration building where the core stage-1 is erected on the mobile platform and the boosters added;

Ariane-502 was generally successful in October 1997. An unanticipated roll torque from the main engine caused premature shutdown of the core stage and resulted in a lowered transfer orbit. The phenomenon was allowed for on subsequent flights. (ESA/CNES/CSG)

- Bâtiment d'Assemblage Final (BAF) assembly building where the payload composite is assembled and erected, the stage-2 tanks filled and the final electrical checkout conducted;
- Launch Centre (CDL-3) for launch operations with two vehicles simultaneously.

The new 3000 $m^2$ S5 payload processing facility came on line in 2001, designed to handle four large payloads simultaneously, including the Automated Transfer Vehicle. Envisat was the first satellite to use it. A second mobile launch table was added in 2000.

**Ariane-5E** It is clear that the mass of commercial telecommunications satellites destined for geostationary orbit – Ariane's principal market – will continue to grow. Ariane-5's target capacity of 5.97 t into GTO will no longer be able to accommodate two satellites per launch – essential for profitability. The October 1995 ESA Ministerial Council in Toulouse therefore approved the Ariane-5E (E=Evolution) programme to increase dual-payload GTO capacity to 7.4 t, now expected to be available in 2002. Most of the improvement (800 kg) comes from uprating the main engine to the Vulcain-2 model: increasing thrust to 1350 kN by widening the throat 10%, increasing chamber pressure 10%, extending the nozzle and changing the LOX/$LH_2$ mixture ratio. That last element requires the tank bulkhead to be lowered by 65 cm, raising propellant mass to 170 t. Welding the booster casings instead of bolting them together saves 2 t and allows 2430 kg more propellant in the top segment, increasing GTO capacity by 300 kg. A new composite structure for the VEB saves 160 kg. Replacing the Speltra carrier by the lighter Sylda-5 adds 380 kg capacity. Roll control during burns will be provided by a thruster

*Cutaway of the Ariane-5G vehicle on the ELA-3 launch pad. (ESA/D. Ducros)*

**Ariane-5G Principal Characteristics**

**Boosters**
(P230; EAP: Etage d'Accélération à Poudre)

*Principal contractors:* EADS Launch Vehicles (stage integrator), Europropulsion (motors)

*Size:* 31.2 m long, 3.05 m diameter, 40 t empty mass

*Powered by:* 238 t of solid propellant generates 5250 kN each at launch; 132 s burn time

*Design:* motor is assembled in Kourou from three sections, each of 8 mm-thick steel. The two lower sections each comprise three 3.35 m-long cylinders. HTPB solid propellant of 68% ammonium perchlorate, 18% aluminium and 14% liner produced and cast in casings in Kourou; 3.4 m-long forward section shipped already loaded by BPD from Italy. Nozzle steering by two hydraulic actuators using flexbearing for 6° deflection. Plan recovery for inspection of two booster sets annually using parachutes carried in nosecone (GTO penalty 100 kg)

**Stage-1**
(H155; EPC: Etage Principal Cryotechnique)

*Principal contractors:* EADS Launch Vehicles (stage integrator), Snecma Moteurs (main engine), Cryospace (tanks)

*Size:* 30.7 m long; 5.40 m diameter, 12.6 t dry mass

*Powered by:* one Snecma Moteurs Vulcain cryogenic engine providing 900 kN at launch, increasing to 1145 kN (vacuum thrust) for 580 s, gimballed for attitude control, drawing on 156 t of liquid oxygen (LOX) and liquid hydrogen ($LH_2$)

*Design:* the aluminium tank is divided into two sections by a common bulkhead, creating a 120 $m^3$ LOX forward tank (pressurised to 3.5 bar by helium) and a 390 $m^3$ $LH_2$ aft tank (pressurised to 2.5 bar by gaseous $H_2$). The tank's external surface carries a 2 cm-thick insulation layer to help maintain the cryogenic temperatures

**Stage-2**
(L9; EPS: Etage à Propergols Stockable)

*Principal contractor:* Astrium GmbH (Bremen)

*Size:* 3.3 m long; 3.94 m diameter, 1.2 t dry mass

*Powered by:* Astrium Aestus reignitable gimballed engine providing 27.5 kN for 1100 s, drawing on up to 9.7 t of NTO/MMH

*Design:* this orbit injection stage also ensures payload orientation and separation. Required to nestle inside the VEB under the payload fairing, it is designed for compactness: the engine is embedded within the four propellant spheres (each 1.41 m-diameter, pressurised to 18.8 bar by helium). Main structural element is frustum continuing VEB's frustum at 3936 mm-diameter lower face and supporting payload adapters on 1920 mm-diameter forward face

**Vehicle Equipment Bay** (VEB)

*Principal contractor:* Astrium SA

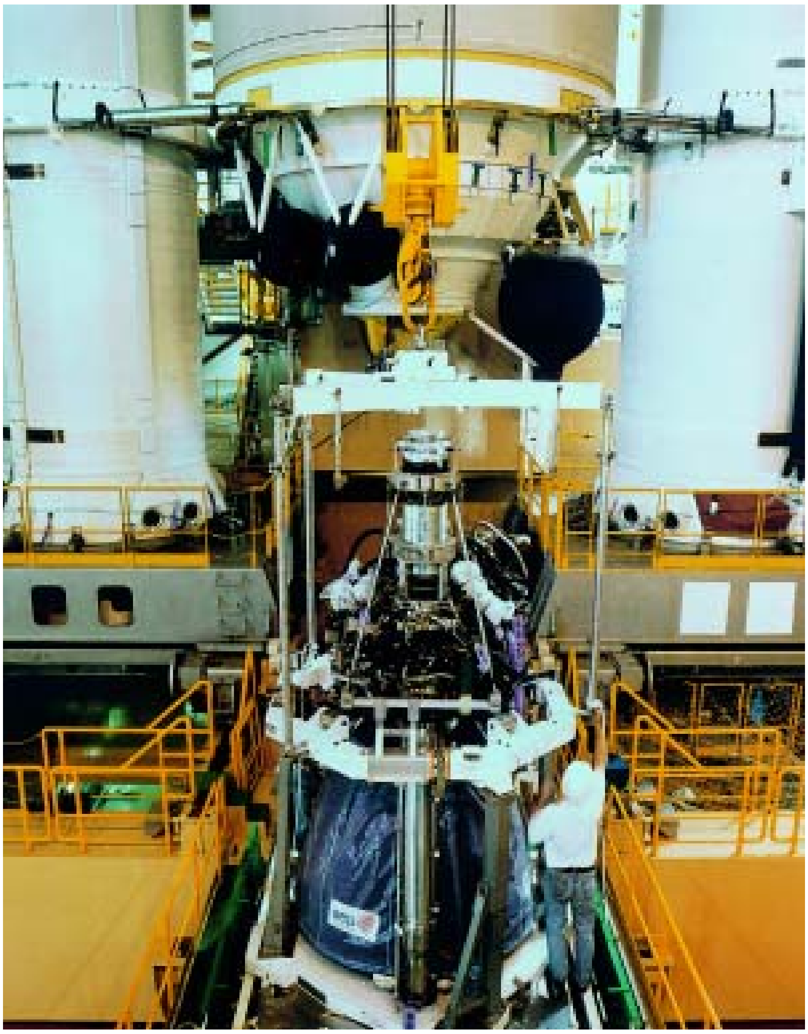
*Purpose:* carries equipment for vehicle guidance, data processing, sequencing, telemetry and tracking

*Size:* 104 cm high; 4.0 m diameter, 520 kg

*Design:* internal frustum of a CFRP sandwich supports upper stage at its 3936 mm-dia forward end; external aluminium cylinder supports payload fairing/carrier; annular platform carries the electronics. Hydrazine thrusters provide roll control during stage-1/2 burns, and 3-axis control after stage firings

**Payload Fairing and Carriers**

Payloads are protected by a 2-piece aluminium fairing until it is jettisoned after about 285 s during the stage-2 burn. Prime contractor is Contraves. Three basic lengths are available: 12.7, 13.8 and 17 m; dia 5.4 m. The initial main payload carrier is the Spelda, which sits between the fairing and stage-2/VEB, housing one satellite internally and a second on its top face, under the fairing. Two models: 5.5 m & 7 m heights. To be replaced in 2002 by Sylda-5, sitting inside standard fairings: 6 versions, 4.9-6.4 m heights, 4.6 m inner dia. Four extension rings available for fairing, increase heights by 0.50-2.0 m. Some missions can also carry up to six 50 kg satellites as passengers on ASAP-5 adapter.

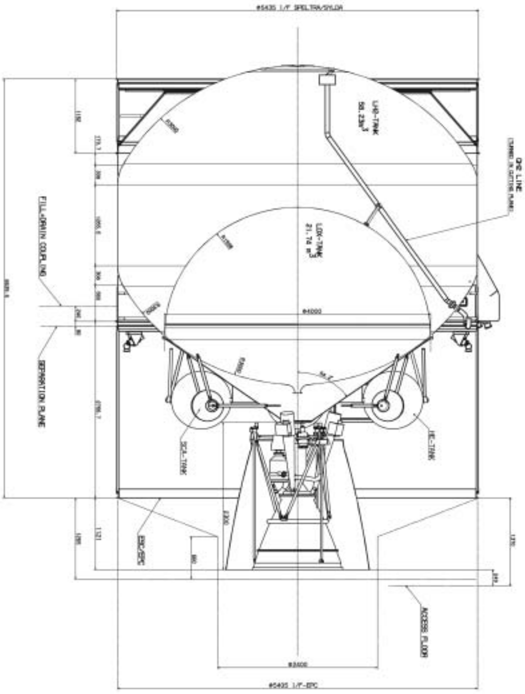


*Preparing to install the Vulcain main engine on Ariane-5. (ESA/CNES/CSG)*

*Ariane-5's upper stage is designed for compactness, nestling the engine among clustered propellant tanks. (ESA/CNES/CSG)*

*Ariane-5's Vehicle Equipment Bay (VEB) carries the control systems. Stage-2 sits on the inner truncated cone.*

*The baseline ESC-B cryogenic stage.*



| Ariane-5 Performance (kg) | | | | |
|---|---|---|---|---|
| | *Ar-5G* | *Ar-ESV* | *Ar-ECA* | *Ar-ECB* |
| **GTO**[1] | 5860[2] | 7100[2]/7400[3] | 9400[3] | 12 000[3] |
| **SSO**[4] | 9216 | 12 800 | n/a | 13 300 |
| **LETO**[5] | 17 910 | n/a | n/a | n/a |

1: 600x36 000 km, 7°, short fairing. 2: Speltra. 3: Sylda-5. 4: Sun-synchronous 800x800 km, 98.6°, long fairing. 5: low Earth transfer orbit 50x300 km, 51.6°, long fairing

**Ariane-5 Batches**

The first two Ariane-5s were funded as part of the development programme. Arianespace ordered its first P1 batch of 14 Ariane-5G (G=generic) vehicles in June 1995. The contracts for the P2 batch were signed in 2000: three are Ar-5G and 17 Ar-5E. Half will have EPS-V upper stages and the rest ESC-A. The first launch, in 2002, will be of an Ar-5ECA. The cost reduction in comparison with P1 is 35%. The goal for batch P3 – which will include Ar-5ECB versions – is a 50% cost reduction with respect to P1.

package on the EPC core, simplifying the EPS control thrusters.

But even these improvements are not enough to remain competitive, as market projections predict launches of paired 6 t satellites will be required by 2006. ESA's Council in June 1998 therefore approved the Ariane-5 Plus programme to meet this challenge. Improvements will be phased in:

**Ariane-5ESV** (V=Versatile) will allow multiple EPS stage-2 reignitions to accommodate a wider range of missions. Stretched tanks add 250 kg of propellant. Coasting between burns requires a 6 h life, provided by improving thermal protection and enhanced batteries.

**Ariane-5ECA** (C=Cryogenic) will provide 10 t (9.4 t for dual satellites) into GTO using the ESC-A cryogenic stage-2 powered by the 64.8 kN HM7B engine from Ariane-4. Propellant mass is 14.4 t, diameter 5.4 m. Single ignition. Reuses the Ar-4 LOX tank and thrust frame, plus the Ar-5 EPC tank bulkhead. Debut is planned for mid-2002 as the first Ariane-5E launch.

**Ariane-5ECB** requires the approval of the Ministerial Council meeting in 2001. It offers 12 t GTO capacity in 2006 using the ESC-B stage-2, derived from ESC-A. The new 155 kN Snecma Moteurs Vinci engine offers multiple (1-5) ignitions, drawing on 24 t of $LOX/LH_2$. Vinci uses the expander cycle, in which the turbines are driven by hydrogen heated through the walls of the combustion chamber before being injected. SI 464 s, combustion pressure 280 bar, expansion ratio 280, mixture ratio 5.8 ($LOX/LH_2$), flow rates 28.8/5 kg/s ($LOX/LH_2$), mass 480 kg, height 4.20 m, exit diameter 2.10 m.

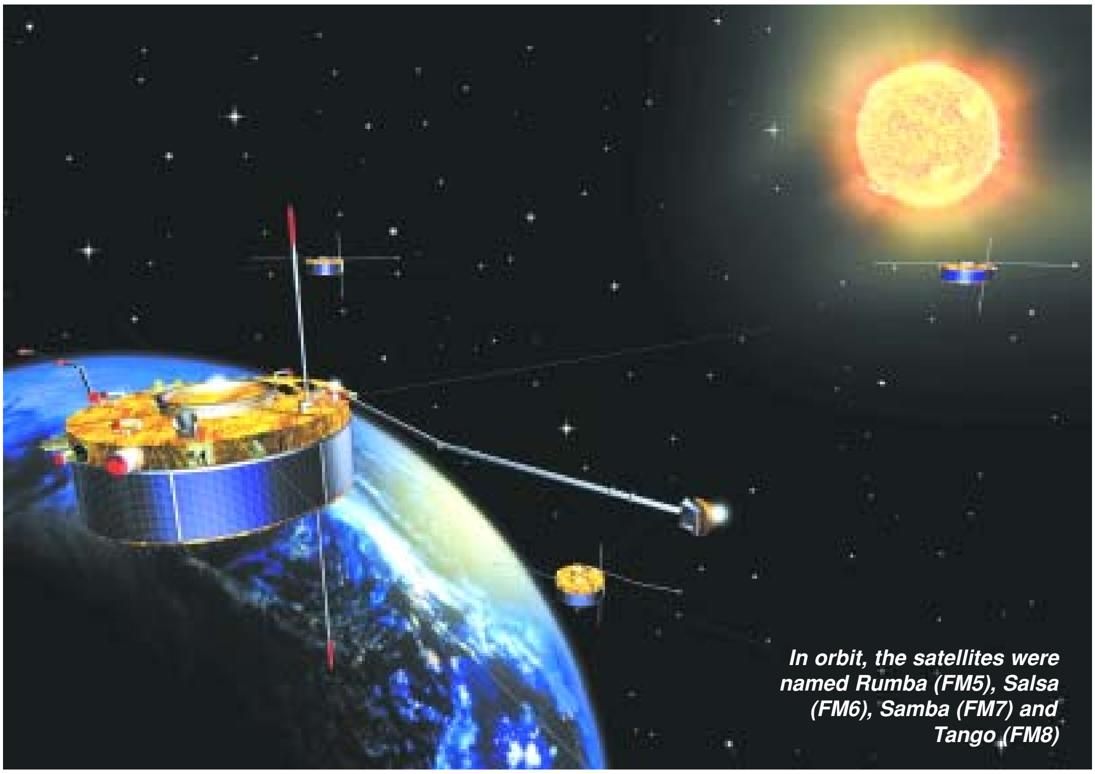
Payloads will undoubtedly continue to grow, so a 15 t GTO capacity may be necessary by 2010. Ariane-5 was designed with a large growth potential – the Hermes spaceplane required a large lower composite that is oversized for the current upper elements. Adopting the P80 solid motor (being developed in parallel with the Vega launcher) for the boosters would add some 1 t GTO capacity. Other improvements could include an uprated Vulcain-3.

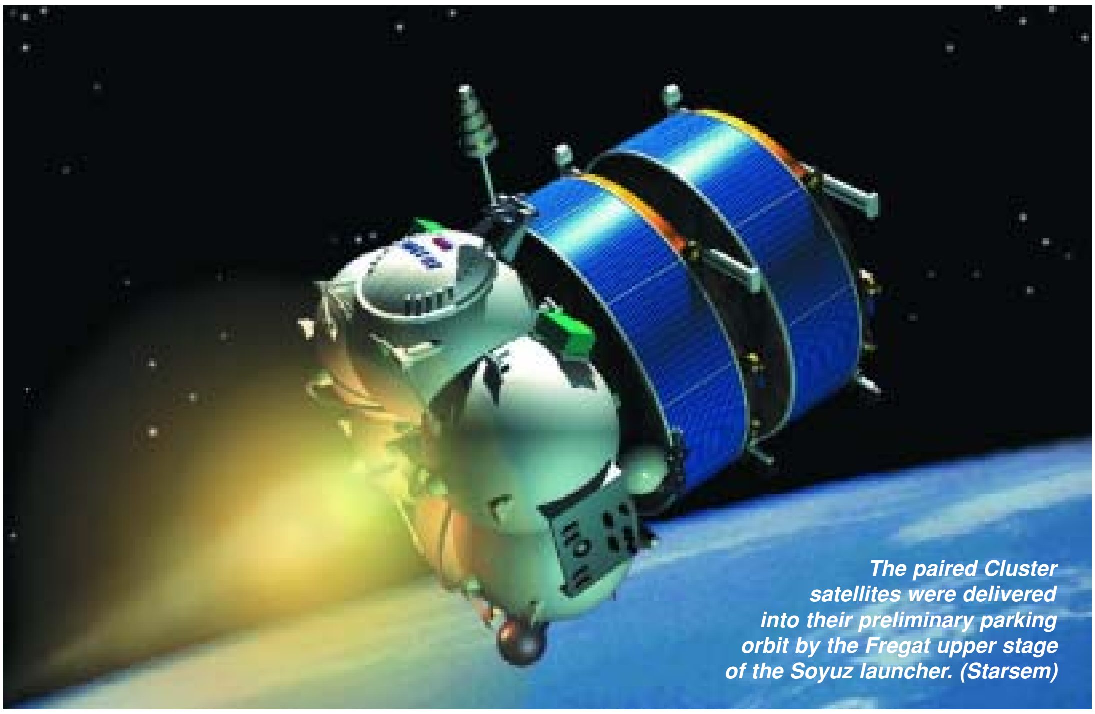
# Cluster

*Achievements:* most comprehensive and detailed observations of magnetosphere and its environment
*Launch dates:* FM1-FM4 4 June 1996 (launch failure); FM6/FM7 16 July 2000; FM5/FM8 9 August 2000
*Mission end:* planned formally January 2003, but extension possible
*Launch vehicle/site:* FM1-FM4 Ariane-501 from ELA-3, Kourou, French Guiana; FM5-FM8 in pairs on Soyuz-Fregats from Baikonur Cosmodrome, Kazakhstan
*Launch masses:* FM1 1183 kg; FM2 1169 kg; FM3 1171 kg; FM4 1184 kg; FM5 1183 kg; FM6 1193 kg; FM7 1181 kg; FM8 1195 kg. 650 kg propellant, 72 kg science payload
*Orbits:* FM1-FM4 planned 25 500x125 000 km, 90° (via 10° GTO); FM5-FM8 delivered into 250x18 050 km, 64.8°, used onboard propulsion in 5 burns to attain 23 600x127 000 km, 90.5°, formation flying began 16 August 2000
*Principal contractors:* Dornier (prime), MBB (solar array, thrusters), British Aerospace (AOCS, RCS), FIAR (power), Contraves (structure), Alcatel (TT&C), Laben (OBDH), Sener (booms)

The Cluster mission was proposed to the Agency in late 1982 and subsequently selected, with Soho, as the Solar Terrestrial Science Programme, the first Cornerstone of ESA's Horizon 2000 Programme. The mission is investigating plasma processes in the Earth's magnetosphere using four identical spacecraft simultaneously. It is accurately measuring 3-D and time-variable phenomena, making it possible to distinguish clearly between spatial and temporal variations for the first time.

The four Cluster spacecraft are in almost identical, highly eccentric polar orbits, essentially fixed inertially so that in the course of the nominal 2-year mission a detailed examination can be made of all the significant regions of the magneto-sphere. With summer launches, the plane of this orbit bisects the geomagnetic tail at apogee during the summer, and passes through the northern cusp region of the magnetosphere 6 months later. Thrusters are being used to change the in-orbit constellation of the satellites periodically by modifying their separations to between 200 km and 18 000 km to match the scale lengths of the plasma phenomena under investigation (600 km was established for the February 2001 cusp crossings). As the original Cluster mission took advantage of a cheap Ariane-5 GTO demonstration launch, the satellites carried high propellant loads to attain their required orbits. Unfortunately, the spacecraft were lost in the launch failure. ESA's Science Programme Committee on 3 April 1997 approved


In orbit, the satellites were named Rumba (FM5), Salsa (FM6), Samba (FM7) and Tango (FM8)


The paired Cluster satellites were delivered into their preliminary parking orbit by the Fregat upper stage of the Soyuz launcher. (Starsem)

the replacement mission. Only three new satellites required ordering from Dornier in November 1997; the first (FM5) was quickly assembled from spares. The spacecraft are essentially identical to their predecessors, but some electronic components were no longer available. The solid-state recorders are new designs, with increased capacities. The high-power amplifiers, previously provided by NASA, were procured in Europe. Minor modifications shortened the experiment-carrying radial booms to fit the spacecraft inside the Soyuz payload fairing. Also, the main ground antenna at Odenwald (D) was replaced by Villafranca (E).

Cluster commissioning began 16 August 2000 when they had rendezvoused in the planned orbit. First, the ASPOC and CIS covers were opened and all rigid booms were deployed. The magnetometers on all four craft were then commissioned. The instruments were split into two groups: the wave instruments were commissioned on two spacecraft while the particle instruments were commissioned on the other pair. This avoided conflict between deploying the 44 m-long wire booms (four on each craft) and commissioning the particle instruments. This took about 1.5 months; work then began on the other half. During commissioning, ASPOC failed on FM5 (high-voltage control) and CIS on FM6 (power supply). Formally, science operations began 1 February 2001.

The first glimpse of the fluctuating magnetic battleground came on 9 November 2000 when the quartet made their first crossings of the magnetopause. Data clearly showed that gusts in the solar wind were causing the magnetosphere to balloon in and out, meaning the satellites were alternately inside and outside Earth's magnetic field. For the first time, simultaneous measurements were made on both sides of the magnetopause. An early achievement was the first observational proof by STAFF and FGM of waves along this shifting boundary.

By late December 2000, the quartet moved close to the bow shock – 100 000 km on Earth's sunward side – where solar wind particles are slowed to subsonic speeds after slamming into Earth's magnetic shield at more than 1 million km/h. Cluster's instruments began to record in great detail what happens at this turbulent barrier. Again, the buffeting solar wind shifted the bow shock back and forth across the spacecraft at irregular intervals. The bow shock had never been seen before in such detail.

The first observations of the north polar cusp were made on 14 January 2001, when shifts in the solar wind caused the spacecraft to pass right through this narrow 'window' in the magnetic envelope at an altitude of about 64 000 km. The EISCAT ground-based radar in Svalbard, which lay beneath the Cluster spacecraft at that time, confirmed the abrupt change in the cusp's position.

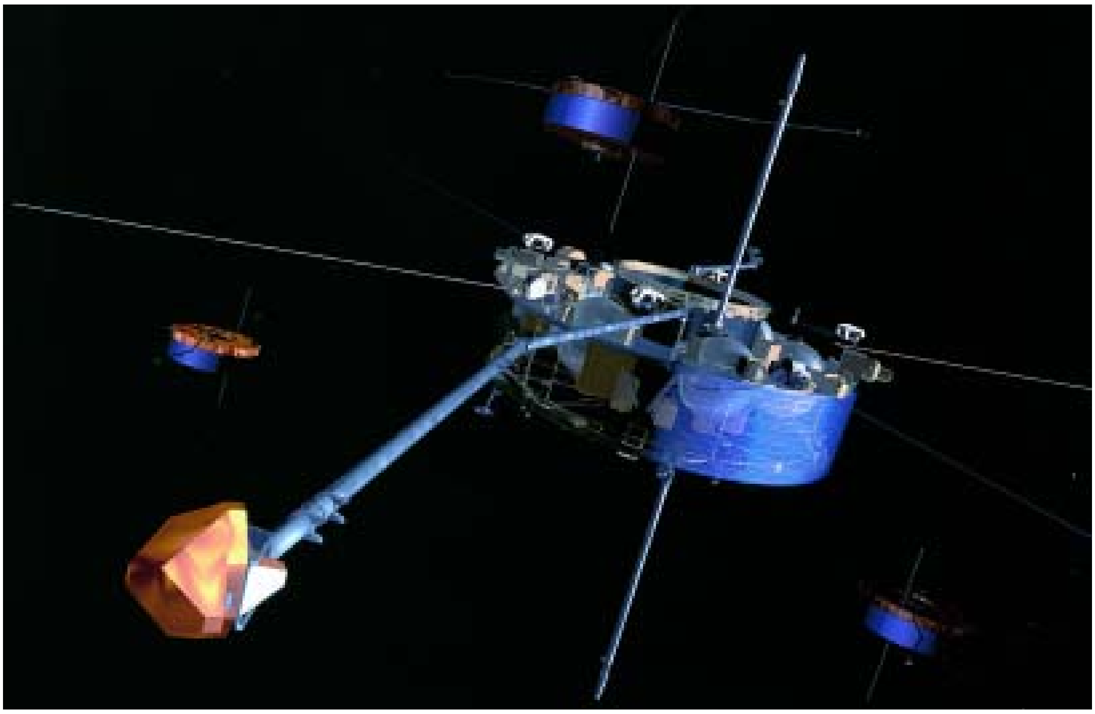
The different data sets will provide valuable new insights into the physical processes in these key regions above the Earth's magnetic poles. This very dynamic region had been studied previously only by single satellites.

During 10 May - 3 June 2001, 28 burns increased the satellite separations to 2000 km for 6 months of magnetotail observations. By August, the apogee was centred in the tail.

*The mating of the ring-shaped main equipment platform of FM6 with its cylindrical central section took place on 2 November 1998 at prime contractor Dornier Satellitensysteme in Friedrichshafen, Germany. A team of about 30 spent the next 2 months attaching the 11 scientific experiments to the aluminium structure and completing assembly. Several more months of testing followed before the spacecraft was delivered to IABG in Munich for further trials.*

**Double Star: Two More Cluster-type Satellites**

Cluster will be joined by China's two Double Star (DSP) satellites carrying some Cluster flight spare instruments. Launched in December 2002 and March 2003, they will provide complementary observations from equatorial (apogee 60 000 km) and polar (apogee 25 000 km) orbits, respectively. The nine European instruments will be ASPOC, FGM, PEACE, STAFF-DWP, Energetic Particle Spectrometer, Hot Ion Analyser and Neutral Atom Imager. The agreement with the Chinese National Space Administration was signed at ESA HQ on 9 July 2001; the cost to ESA is €8 million.



*Bottom: at Baikonur preparing for launch.*

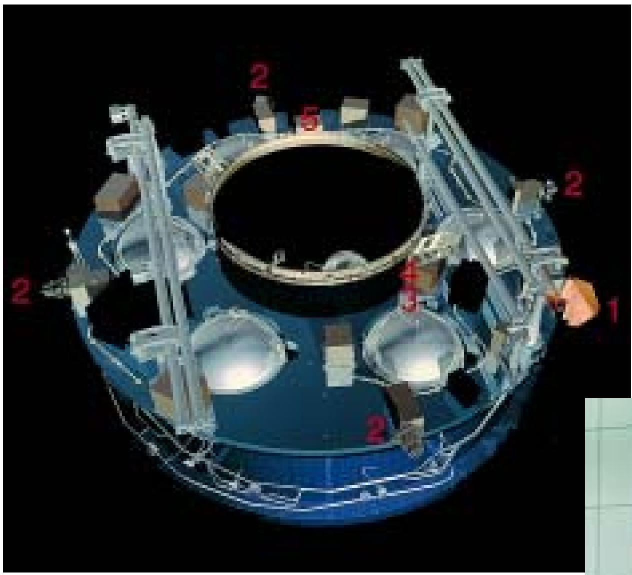

FM1-FM4 at IABG in Ottobrun, Germany. (DASA)

*Satellite configuration:* spin-stabilised 2.9 m-dia cylinder, 1.3 m high, with conductive surfaces, solar array mounted on body, two 5 m-long radial booms carry magnetic field instruments, two pairs of 100 m tip-to-tip wire antennas for electric field measurements. The structure is based around a central CFRP cylinder supporting the main equipment platform (MEP), an aluminium-skinned honeycomb panel reinforced by an outer aluminium ring, supported by CFRP struts connected to the cylinder. Six cylindrical titanium propellant tanks with hemispherical ends are each mounted to the central cylinder via four CRFP struts and a boss. Six curved solar-array panels together form the outer cylindrical shape of the spacecraft body and are attached to the MEP. The MEP provides the mounting area for most of the spacecraft units, the payload units being accommodated on the upper surface and the subystems, in general, on the lower surface. The five batteries and their regulator units that power the spacecraft during eclipse are mounted directly on the central cylinder.

*Attitude/orbit control:* spin-stabilised at 15 rpm in orbit; attitude determination better than 0.25° by star mapper and Sun sensor. RCS of eight 10 N MON/MMH thrusters. Single 400 N MON/MMH motor raised parking orbit into operational orbit in five firings consuming 500 kg propellant.

*Power system:* silicon-cell solar array on cylindrical body sized to provide 224 W (payload requires 47 W); five silver-cadmium batteries totalling 80 Ah provide eclipse power

*Communications:* science data rate transmitted at 16.9 kbit/s realtime (105 kbit/s burst mode) or stored on two 3.7 Gbit (2.25 Gbit FM1-FM4) SSRs for later replay. Telemetry downlink 2-262 kbit/s at S-band (2025-2110/2200-2290 MHz up/down) at 10 W. Data from four satellites synchronised via highly stable onboard clock and time stamping at ground stations. Operated from ESOC via Villafranca (E). Science operations coordinated through a Joint Science Operations Centre in the UK; data distributed via Cluster Science Data System (CSDS), using internet to transfer to centres in Austria, France, Germany, Hungary, Scandanavia, Netherlands, UK, China and US.




*The five Wave Experiment Consortium instruments on Cluster-II. 1: Spatio-Temporal Analysis of Field Fluctuations (STAFF). 2: Electrical Field & Wave (EFW). 3: Digital Wave Processing (DWP). 4: Waves of High Frequency and Sounder for Probing of Density by Relaxation (WHISPER). 5: Wideband Data (WBD). (ESA/VisuLab)*

*Cluster FM3 at prime contractor Dornier. (DASA)*

| Cluster Scientific Instruments | |
|---|---|
| **FGM** | Fluxgate Magnetometer (2 on 5 m boom; DC to ~10 Hz). PI: A. Balogh, Imperial College, UK |
| **STAFF** | Spatio-Temporal Analysis of Field Fluctuations (3-axis search coil on 5 m boom; wave form to 10 Hz). PI: N. Cornilleau-Wehrlin, CETP, F |
| **EFW** | Electric Fields & Waves (paired 88 m wire booms; wave form to 10 Hz). PI: M. Andre, IRFU, S |
| **WHISPER** | Waves of High Frequency and Sounder for Probing of Density by Relaxation (total electron density, natural plasma waves to 400 kHz). PI: P.M.E. Décréau, LPCE, F |
| **WBD** | Wide Band Data (high frequency electric fields of several 100 kHz). PI: D.A. Gurnett, Iowa Univ., USA |
| **DWP** | Digital Wave Processor (controls STAFF, EFW, WHISPER, WBD wave consortium experiments). PI: H. Alleyne, Sheffield Univ., UK |
| **EDI** | Electron Drift Instrument (measurement of electric field by firing electron beam in circular path for many tens of km around satellite, detector on other side picks up return beam; 0.1-10 mV/m, 5-1000 nT). PI: G. Paschmann, MPE, D |
| **CIS** | Cluster Ion Spectrometry (composition/dynamics of slowest ions, 0-40 keV/q). PI: H. Rème, CESR, F |
| **PEACE** | Plasma Electron/Current Analyser (distribution, direction, flow and energy distribution of low/medium-energy electrons; 0-30 keV). PI: A. Fazakerley, MSSL, UK |
| **RAPID** | Research with Active Particle Imaging Detectors (energy distribution of 20-400 keV electrons & 2-1500 keV/nucleon ions). PI: P. Daly, MPAe, D |
| **ASPOC** | Active Spacecraft Potential Control (removal of satellite excess charge by emitting indium ions, current up to 50 mA). PI: K. Torkar, IWF, A |

# Huygens

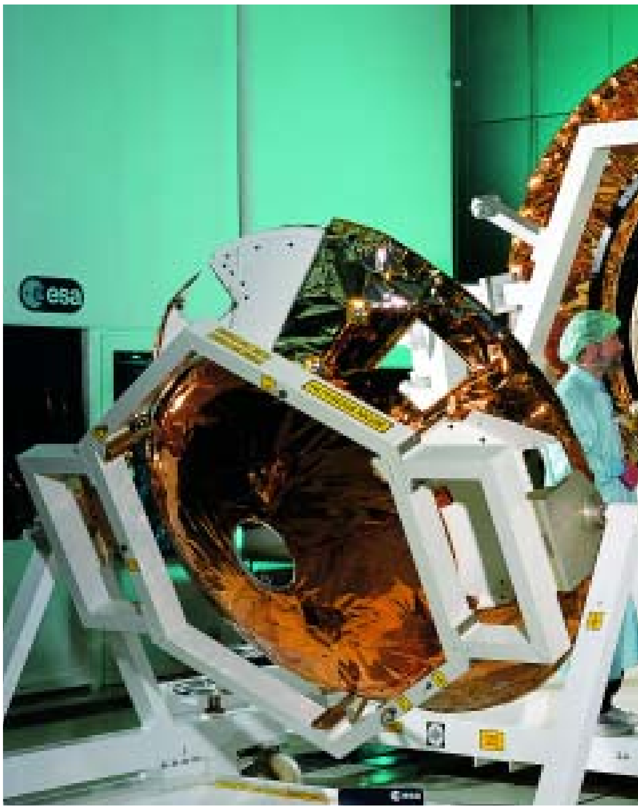
*Achievements:* first probe to Titan, first ESA planetary mission
*Launch:* 08.43 UT 15 October 1997 by Titan-4B from Cape Canaveral Air Force Station, Florida
*Mission end:* planned 27 November 2004 (Titan entry/descent/landing)
*Launch mass:* 348.3 kg total (318.3 kg entry Probe; 30.0 kg Orbiter attachment). Cassini/Huygens total launch mass 5548 kg
*Orbit:* interplanetary, using gravity assists at Venus (26 April 1998; 24 June 1999), Earth (18 August 1999) and Jupiter (30 December 2000)
*Principal contractors:* Aerospatiale (prime, thermal protection, aerothermodynamics); DASA (system integration & test; thermal control)

The Huygens Probe is ESA's element of the joint Cassini/Huygens mission with NASA to the Saturnian system. Huygens is being carried by NASA's Orbiter to Saturn, where it will be released to enter the atmosphere of Titan, the planet's largest satellite and the only one in the solar system with a thick atmosphere. The Probe's primary scientific phase will occur during the 2-2.5 h parachute descent, when the six sophisticated instruments will study the complex atmosphere's chemical and physical properties. Although Titan is too cold (–170°C at the surface) for life to have evolved, it offers the unique opportunity for studying pre-biotic chemistry on a planetary scale.

On arrival at Saturn, Cassini/Huygens will make its closest approach to the planet, passing only 20 000 km above the cloud tops. Cassini will fire one of its two redundant 445 N engines on 1 July 2004 for 96 min to slow by 622 m/s for Saturn Orbit Insertion (SOI); braking into a 1.33x178 Saturn radii ($R_S$), 148-day, 16.8° orbit will consume 830 kg of the 3000 kg main propellant supply. A 50-min, 335 m/s burn 13 days after apoapsis on the first orbit will raise periapsis to 8.2 $R_S$ to target the Orbiter for the first Titan encounter and Huygens' entry.

On 6 November 2004, Cassini/Huygens will manoeuvre on to an impact trajectory with Titan. Two days later, the Orbiter will turn to orient the Probe to its entry attitude, spin it up to 7 rpm, and release it at 0.3 m/s. Huygens will hit the atmosphere at 6 km/s at an entry angle of –64°, aiming for a dayside landing 18.4°N of Titan's equator, 200°E of the sub-Saturn point.

The entry configuration consists of the 2.75 m-diameter 79 kg 60° half-



### Mission Modification

Twice a year, Huygens is activated for 3 h and checked out, allowing regular calibration of the instruments and subsystems. An end-to-end test of the radio relay link during the 5th checkout, in Feb 2000 (supported by further tests using the Probe Engineering Model at ESOC in Sep-Dec 2000) revealed that the bandwidth of the Huygens receiver on Cassini is too narrow to cope with the expected Doppler shift during descent. An ESA/NASA Huygens Recovery Task Force was set up to recommend a new mission scenario to avoid data loss; a final decision was awaited as this volume was completed.

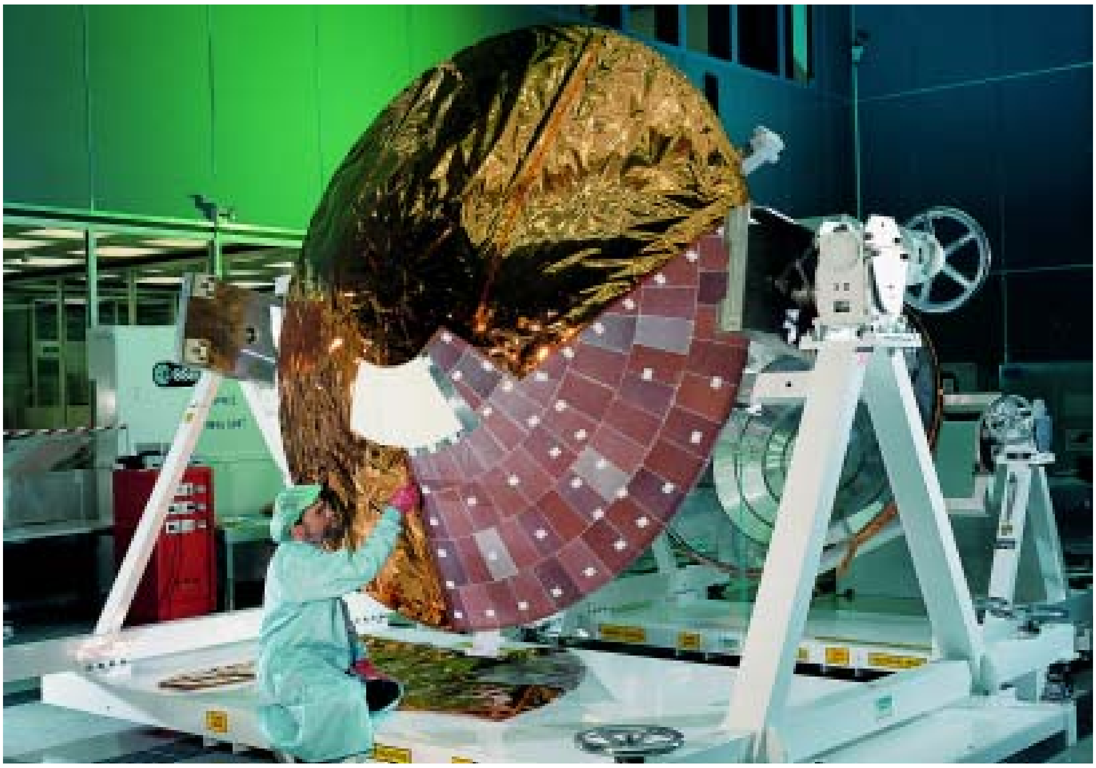
angle coni-spherical front heatshield and the aluminium back cover, providing thermal protection as Huygens decelerates to 400 m/s (Mach 1.5) within 3 min as it reaches 165 km altitude.

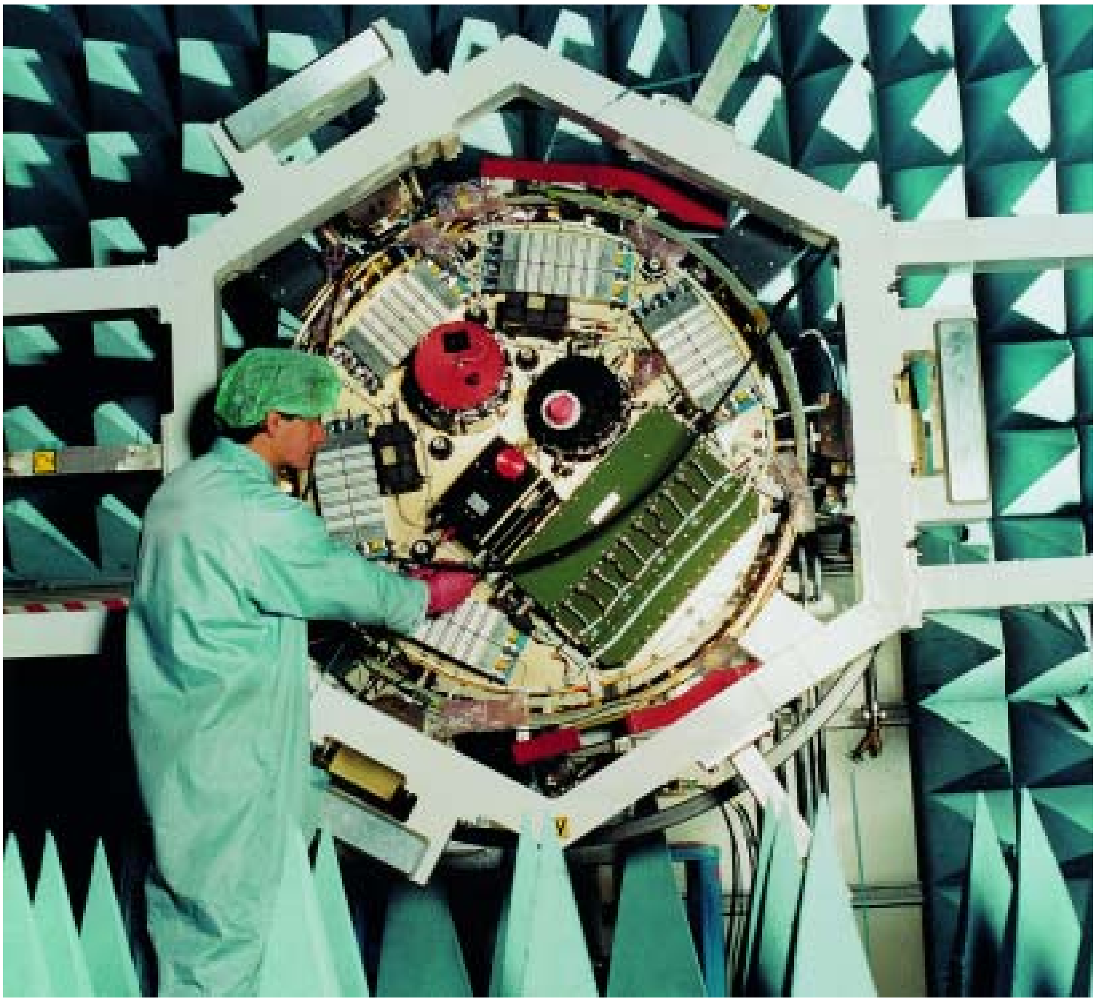
At Mach 1.5, the parachute deployment sequence begins as a mortar extracts the 2.59 m-diameter pilot 'chute which, in turn, pulls away the back cover. After inflation of the 8.30 m-diameter main parachute to decelerate and stabilise Huygens through the transonic region, the front shield is released at Mach 0.6 to fall from the Descent Module (DM). Then, after a 30 s delay to ensure that the shield is sufficiently far below the DM to avoid instrument contamination, the GCMS and ACP inlet ports are opened and the HASI booms deployed. The main parachute is sized to pull the DM safely out of the front shield; it is jettisoned after 15 min to avoid a lengthy descent and a smaller 3.03 m-diameter parachute is deployed. All parachutes are made of nylon fabric, with Kevlar lines.

Resources are sized, with a comfortable margin, for a maximum descent of 2.5 h and at least 3 min on the surface. After separation from the Orbiter, Huygens' only power is from five lithium batteries.

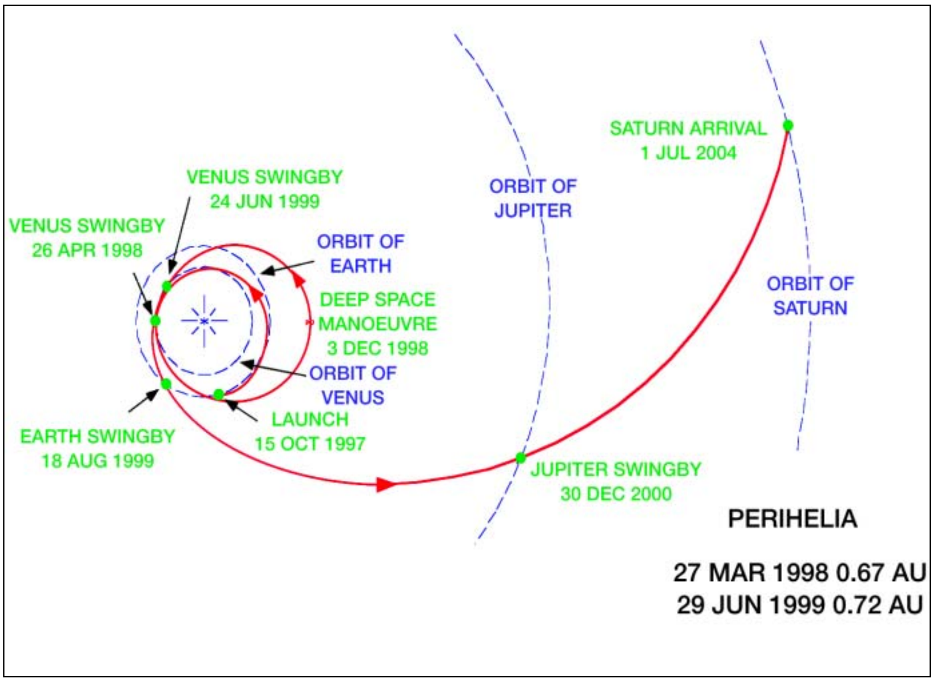
*Huygens' Descent Module is attached to the rear of the front shield, which will protect the DM from the intense heat of entry. The central canister contains the mortar that begins the 2-2.5 h parachute descent phase by firing a small deployment parachute through a membrane in the centre of the back cover (at left), which then itself is detached by the parachute's drag. The main and stabiliser 'chutes are stored in the large box. Also visible on the DM's top face are the two redundant (black conical) antennas that will transmit the data back to the Cassini Orbiter. At the 11 o'clock position is the CD carrying more than 100 000 signatures and messages.*

The 2.7 m-diameter front shield provides the main thermal protection during entry. The silica-felt tiles are glued to the CFRP structure. Multi-layer insulation blankets provide benign thermal conditions during the 6.7-year cruise. The white thin-aluminium 'window' acts as a controlled heat leak.





Bottom view of Huygens' Experiment Platform. The red cylinder is part of the SSP; the black cylinder is the GCMS; the black box is the ACP. The silver boxes are the batteries, connected to the power distribution unit (green box).




*Cassini/Huygens requires several planetary swingbys to gain sufficient speed to reach Saturn within 7 years.*

Instrument operations follow either a time sequence in the higher descent or the radar-measured altitude further down. Huygens will operate autonomously after Orbiter separation, the radio link being one-way for telemetry only. Until separation, telecommands can be sent via an umbilical from the Orbiter (which also provides power), but this is used only during cruise for Huygens' biannual check-outs. There will be no scientific measurements before Titan arrival and Huygens will be switched off during most of the cruise. During the 22-day coast after Orbiter separation, only a triply-redundant timer will be active, to wake up Huygens shortly before the predicted entry. Setting the timer and conditioning the batteries will be the last commands sent from ESOC.

Huygens' goals are to make a detailed in situ study of Titan's atmosphere and to characterise the surface along the descent ground track and near the landing site. After parachute deployment, all instruments will have direct access to the atmosphere to make detailed in situ measurements of structure, composition and dynamics. Images and other surface remote sensing measurements will also be made. As it is hoped that Huygens will survive the 5-6 m/s impact for at least 3 min, the payload can make in situ measurements for a direct characterisation of the surface. Longer would allow a detailed analysis of a surface sample and meteorological studies of the surface weathering and atmosphere dynamics. If everything functions nominally, the batteries can power a 30-45 min extended surface science phase that would be the bonus of the mission.

Huygens will transmit its data to the overflying Orbiter; which will point its high-gain antenna at the 200x1200 km target ellipse for 3 h. The data will be stored by the Orbiter in its two solid state recorders for later transmission to Earth as soon as the HGA can be redirected after Huygens has completed its mission.

| Huygens Scientific Instruments |
|---|
| **Huygens Atmospheric Structure Instrument** (HASI). Objectives: atmosphere T & P profiles, winds, turbulence, conductivity; lightning; surface permittivity & radar reflectivity. PI: M. Fulchignoni, Univ. Paris/Obs. Paris-Meudon. 6.3 kg. Participating: I, A, D, E, F, N, SF, USA, UK, ESA/SSD, IS. |
| **Gas Chromatograph Mass Spectrometer** (GCMS). Objectives: atmosphere composition; aerosol pyrolysis products analysis. PI: H.B. Niemann, NASA Goddard. 17.3 kg. Participating: USA, A, F. |
| **Aerosol Collector & Pyrolyser** (ACP). Objectives: aerosol sampling in 2 layers (150-40 km; 23-17 km altitude) for pyrolysis and injection into GCMS. PI: G.M. Israel, SA/CNRS, France. 6.3 kg. Participating: F, A, USA. |
| **Descent Imager/Spectral Radiometer** (DISR). Objectives: atmosphere composition, energy budget & cloud structure; aerosol properties; surface imaging. PI: M.G. Tomasko, Univ. Arizona, USA. 8.1 kg. Participating: USA, D, F. |
| **Doppler Wind Experiment** (DWE). Objectives: Probe Doppler tracking from Orbiter for zonal wind profile. PI: M.K. Bird, Univ. of Bonn. 1.9 kg. Participating: D, I, USA. |
| **Surface Science Package** (SSP). Objectives: condition & composition of landing site; atmosphere measurements. PI: J.C. Zarnecki, Univ. Kent, UK. 3.9 kg. Participating: UK, F, USA, ESA/SSD, PL. |

*Huygens configuration:* the Probe consists of the Entry Assembly (ENA) cocooning the Descent Module (DM). ENA provides Orbiter attachment, umbilical separation and ejection, cruise and entry thermal protection, and entry deceleration control. It is jettisoned after entry, releasing the DM. The DM comprises an aluminium shell and inner structure containing all the experiments and support equipment, including the parachutes. The DM is sealed except for a 6 cm$^2$ vent hole on the top, and comprises: 73 mm-thick aluminium honeycomb sandwich Experiment Platform (supports most experiments and subsystems); 25 mm-thick aluminium honeycomb sandwich Top Platform, forming the DM's top surface (descent system and RF antennas); After Cone and Fore Dome aluminium shells, linked by a central ring.

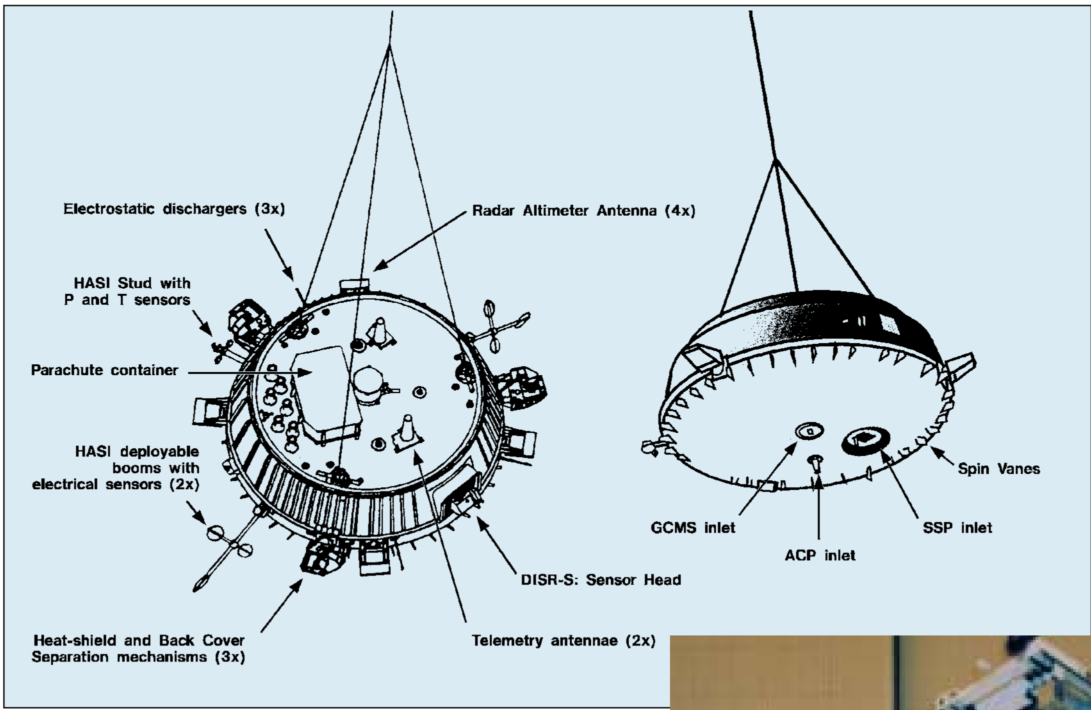
*Attitude/orbit control:* provided by Cassini orbiter; spun up to 7 rpm for release. 36 peripheral DM vanes ensure slow spin (1-2 rpm < 20 km altitude) during descent for azimuthal coverage of some instruments.

*Power system:* five $LiSO_2$ batteries provide total of 2059 Wh, beginning shortly before release: 0.3 W for 22-day coast (to power wake-up timers), 125 W for 18 min pre-entry/entry, 339 W for 80 min descent (without proximity sensing), 351 W for 73 min descent (with proximity sensing), plus up to 45 min of surface activities.

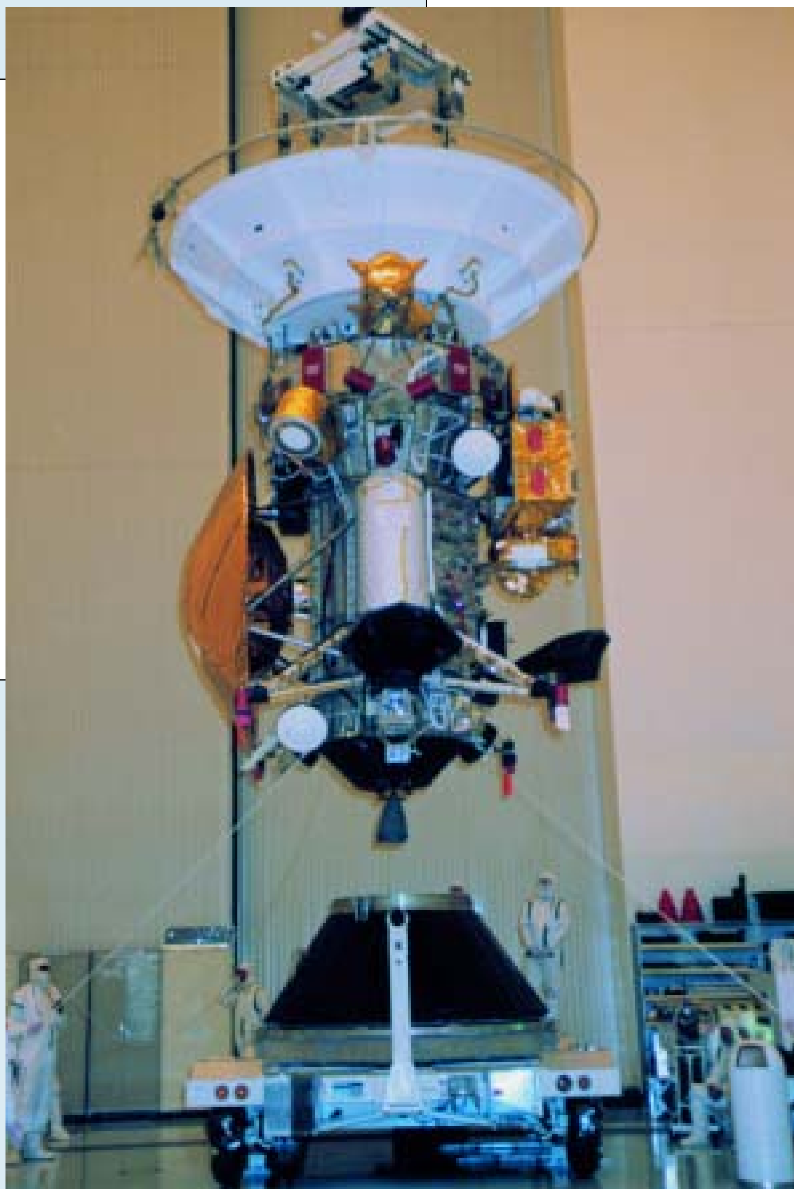
*Thermal protection/control:* tiles of AQ60 ablative material, a felt of silica fibres reinforced by phenolic resin, are glued to the front shield's CFRP honeycomb shell to protect against the 1 MW/m$^2$ entry flux. Prosial, a suspension of hollow silica spheres in silicon elastomer, was sprayed directly on to the shield's rear aluminium structure, where fluxes are ten times lower. The back cover is protected by 5 kg of Prosial. In space, Huygens is insulated from the Orbiter and protected against variations in solar heating (3800 W/m$^2$ near Venus, reducing to 17 W/m$^2$ near Titan) by: multi-layer insulation on all external areas (except for a 0.17 m$^2$ white-painted thin aluminium sheet on the front shield's outer face as a controlled heat leak – about 8 W during cruise); 35 radioisotope heaters on the Experiment and Top Platforms provide continuous 1 W each.

*Communications payload:* two hot-redundant S-band 10 W transmitters and two circular-polarisation antennas (LHCP 2040 MHz; RHCP 2098 MHz) on Huygens broadcast data at 8 kbit/s 41.7 dBm EIRP beginning shortly before entry. No onboard storage. Received by Cassini HGA, recorded and later relayed to Earth.

*Further information can be found at http://sci.esa.int/huygens and in* Huygens: Science, Payload and Mission, *ESA SP-1177, August 1997.*

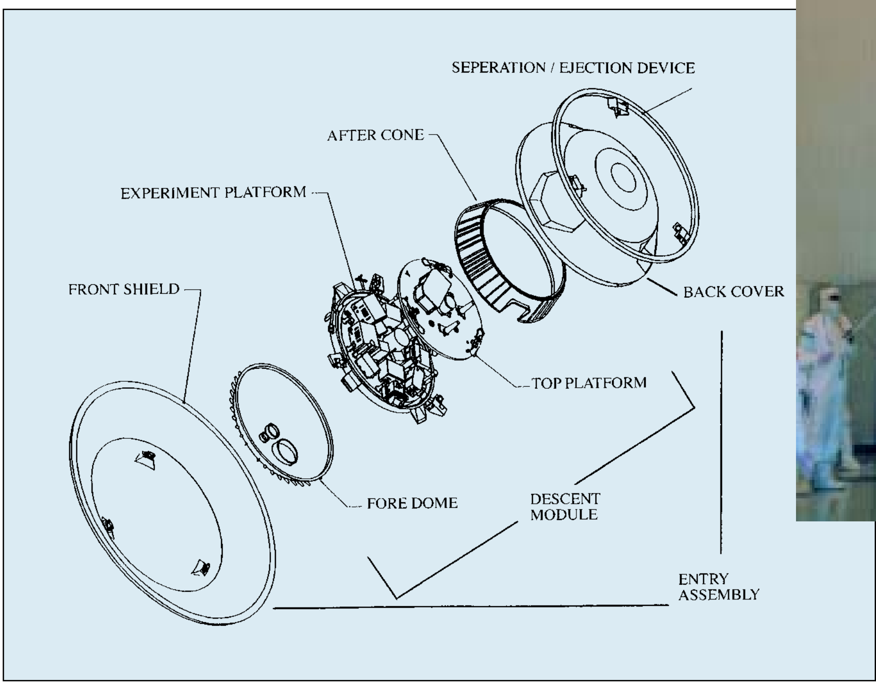



*The Descent Module under its parachute. The HASI booms are deployed and the DISR sensor head can be seen. At right, the GCMS, ACP and SSP view through the fore dome.*



*Cassini, with Huygens mounted on the side, is lowered on to its launch vehicle adapter in the Payload Hazardous Servicing Facility at the Kennedy Space Center. The Huygens Engineering Model is in the Huygens Probe Operations Centre (HPOC) at ESOC being used as a testbed during the cruise to Saturn. (NASA)*

*The principal features of the Huygens Probe.*



# TeamSat

*Achievements:* developed in record time and cost; demonstrated new technologies
*Launch date:* 30 October 1997
*Mission end:* 2 November 1997 (after 3 days when battery expired)
*Launch vehicle/site:* Ariane-502 from ELA-3, Kourou, French Guiana
*Launch mass:* 350 kg
*Orbit:* 540x26 635 km, 8°
*Principal contractor:* ESTEC

TeamSat (Technology, Science and Education Experiments Added to Maqsat) was an initiative of ESTEC's Automation and Informatics Department (now Electrical Engineering in the Directorate of Technical and Operational Support) in response to an invitation from ESA's Launchers Directorate to add experiments to one of the Maqsat instrumented mockups on the Ariane-502 test flight. A principal objective was hands-on involvement of young trainee engineers at ESTEC. The payload was produced in the unprecedented short time of only 7 months from start (December 1996) to readiness (July 1997). Furthermore, costs were kept to a bare minimum (<ECU1 million) through the use of in-house equipment and spares, support from ESTEC staff and the free launch.

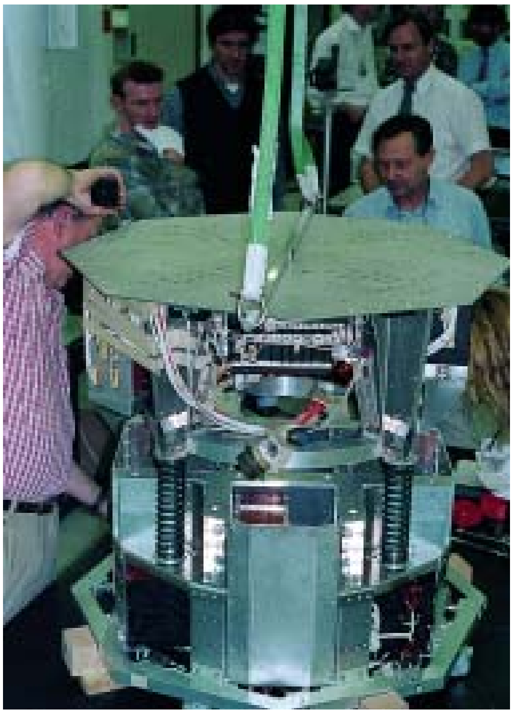
TeamSat was not an independent satellite – most of it remained attached to Ariane's Maqsat-H monitoring payload. The five experiments were (in order of increasing complexity):

**Orbiting Debris Device** (ODD): Maqsat-H was painted 75% white/25% black for optical tracking of the spinning object to help calibrate ground-based telescopes and radars for space debris tracking. Other studies included paint degradation;

**Autonomous Vision System** (AVS): a camera that automatically recognised a non-stellar object and could be used to accurately determine attitude; it could thus be used for navigation and imaging purposes (Technical University of Denmark);

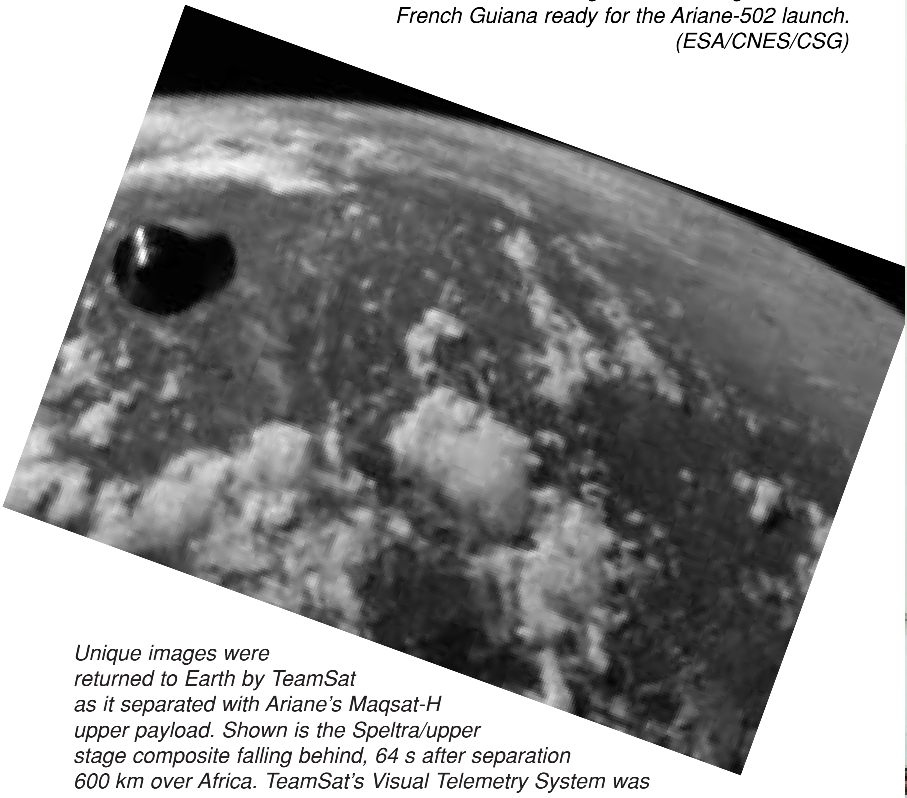
**Visual Telemetry System** (VTS): a system of three cameras with an image compression and storage unit that recorded images of the fairing and satellite separation after launch (Catholic University of Leuven);

**Flux Probe Experiment** (FIPEX): measured the concentration of atomic oxygen up to altitudes of 1000 km. Atomic oxygen is known for its erosion of optical surfaces and lenses;



*TeamSat's first fit-check in the High Bay of ESTEC's Erasmus building of the Team (top) and YES (Young Engineers' Satellite, bottom) systems with the ejection springs in place. (ESA/Andy Bradford)*

Preparing Maqsat-H, with TeamSat attached at bottom, in the Batiment d'Assemblage Final building at Kourou, French Guiana ready for the Ariane-502 launch. (ESA/CNES/CSG)



Unique images were returned to Earth by TeamSat as it separated with Ariane's Maqsat-H upper payload. Shown is the Speltra/upper stage composite falling behind, 64 s after separation 600 km over Africa. TeamSat's Visual Telemetry System was designed to acquire image sequences of critical operations. (ESA)

**Young Engineers' Satellite** (YES): designed, assembled and integrated in record time by young graduates at ESTEC, YES was planned as a tethered subsatellite to be deployed on a 35 km tether. It also contained some additional small experiments, to measure radiation, the solar angle and acceleration in autonomous mode after separation from Maqsat-H. A GPS receiver was also installed, demonstrating the first reception from above the GPS satellite constellation. Unfortunately, the tether was not used because the launch window requirements were changed, resulting in the tether posing a high collision and debris risk. Nevertheless, YES was separated from Maqsat-H (without any tether), and a rehearsal of the tether operations was performed in preparation for a possible future flight.

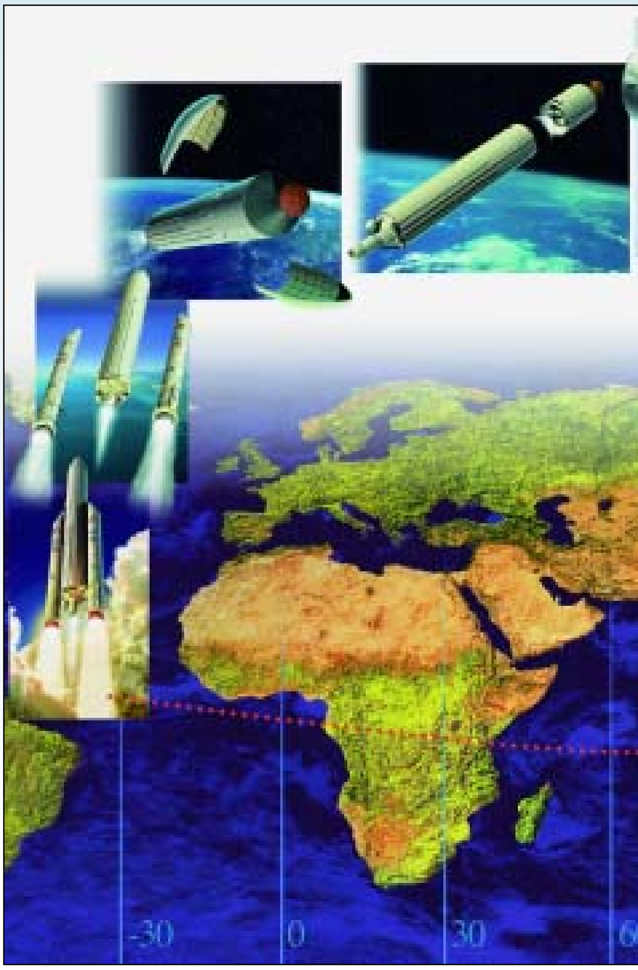
The whole project, particularly YES, evolved for Young Graduate Trainees and Spanish Trainees to gain valuable experience in designing, building and integrating a satellite and its payload. Some 43 young engineers from these schemes, as well as from the Technical University of Delft, were involved at different stages during the satellite production.

From the technology point of view, TeamSat's achievements included:

- use of a quadrifilar helix antenna for 100 MHz to 3 GHz links (to be flown on the Metop weather satellite);
- first fully asynchronous ESA CCSDS-standard packet telemetry system, using new chips for telemetry transfer frame generation;
- provision of telemetry dynamic bandwidth allocation without the use of an onboard computer;
- first ESA spacecraft to use the standard packet-telecommand protocols;
- first demonstration of GPS reception from above the GPS satellite constellation.

# ARD

*Achievements:* ESA's first Earth-return craft, first complete space mission (launch to landing) by Europe
*Launch date:* 16:37 UT, 21 October 1998
*Mission end:* flight duration 101 min, splashing down at 19:28 UT, 21 October 1998
*Launch vehicle/site:* Ariane-503 from ELA-3 complex, Kourou, French Guiana
*Launch mass:* 2716 kg
*Orbit:* suborbital, apogee 830 km above Indian Ocean (5.40°S/78.5°E)
*Principal contractors:* Aerospatiale (prime; contract signed 30 September 1994), Alenia (descent & landing system), DASA (RCS), MMS-France (electronics), SABCA & SONACA (structure)

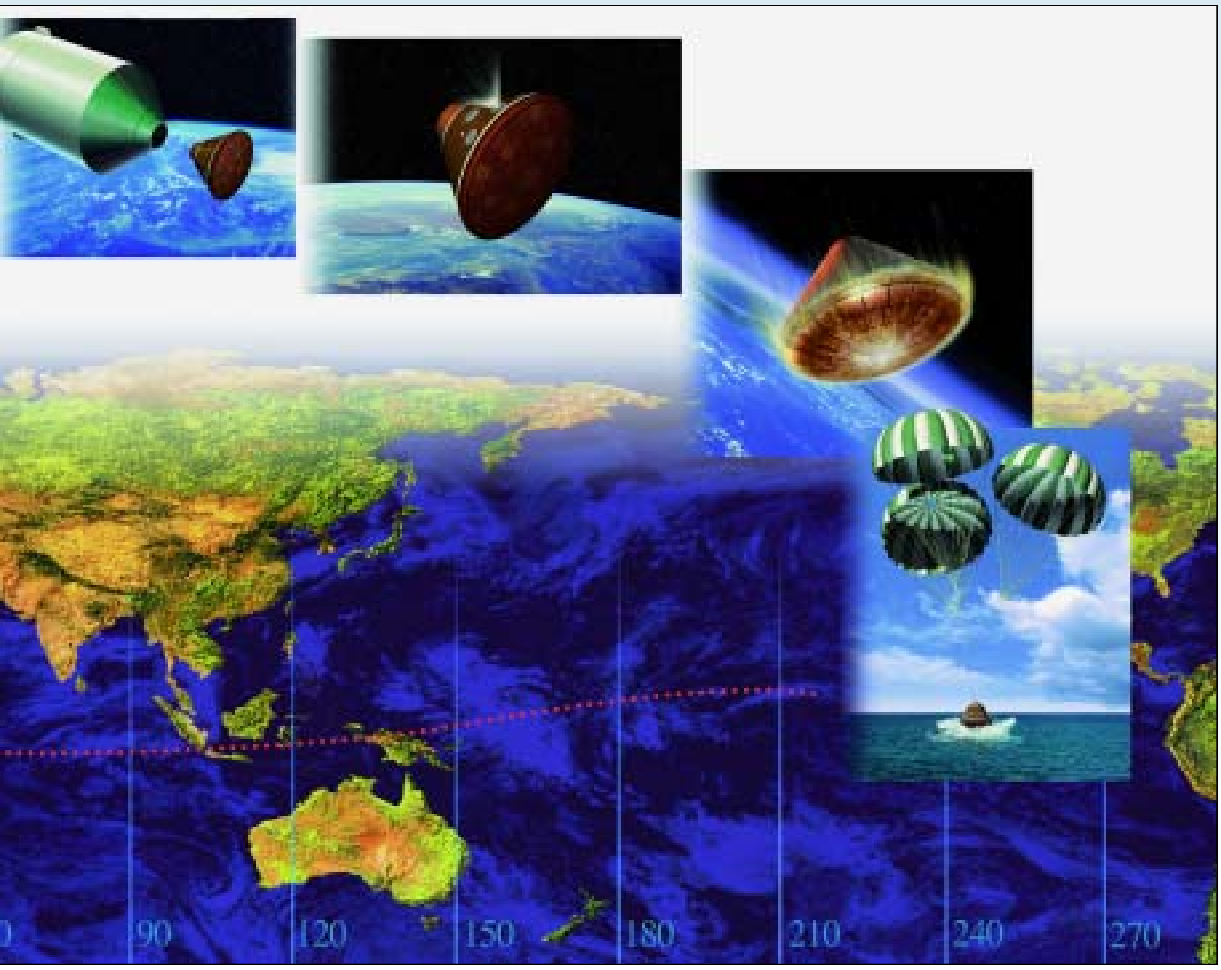



ESA's Atmospheric Reentry Demonstrator (ARD) was a major step towards developing and operating space transportation vehicles capable of returning to Earth, whether carrying payloads or people. For the first time, Europe flew a complete space mission – launching a vehicle into space and recovering it safely.

ARD was an unmanned, 3-axis stabilised automatic capsule launched by an Ariane-5 into a suborbital ballistic path that took it to a height of 830 km before bringing it back into the atmosphere at 27 000 km/h. Atmospheric friction and a series of parachutes slowed it down for a relatively soft landing in the Pacific Ocean, 101 min after launch and three-quarters of the way around the world from its starting point.

ARD's recorded and transmitted telemetry allowed Europe to study the physical environment to which future space transportation systems will be exposed when they reenter the Earth's atmosphere. It tested and qualified reentry technologies and flight control algorithms under actual flight conditions. In particular, it: validated theoretical aerothermodynamic predictions; qualified the design of the thermal protection system and of thermal protection materials; assessed navigation, guidance and control system performances; assessed the parachute and recovery system; and studied radio communications during reentry. ARD provided Europe with key expertise in developing future space transportation and launch vehicles.

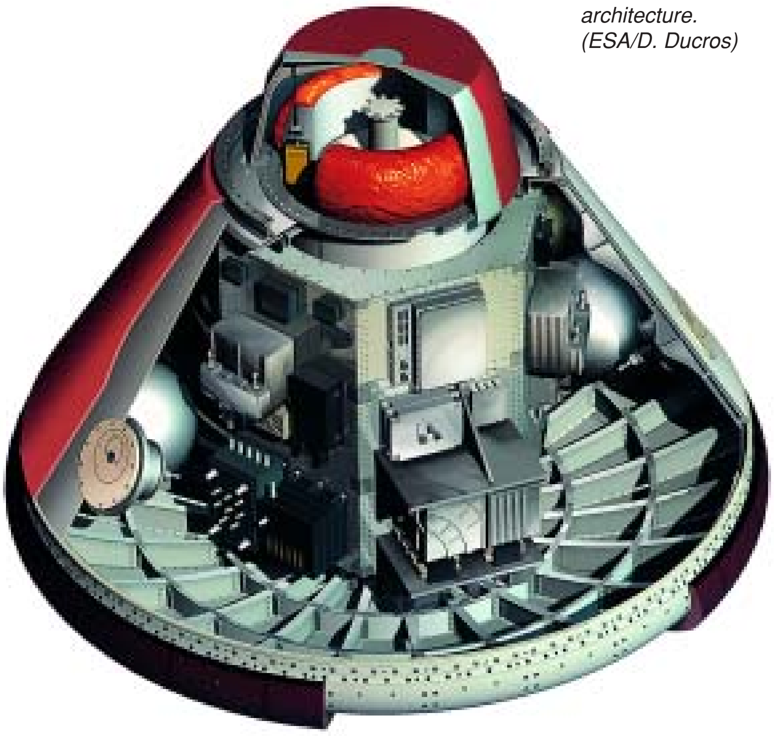
One objective was to validate the flight control algorithms developed as part of the former Hermes spaceplane programme. The guidance algorithm was similar to that used by NASA's Space Shuttle, based on a reference




*Principal stages in the mission of ARD. (ESA/D. Ducros)*

deceleration profile and also used by Apollo. This approach provided good final guidance accuracy (5 km; achieved 4.9 km) with limited real-time calculation complexity. In order to reach the target and to hold deceleration levels to 3.7 *g* and thermal flux within acceptable limits, ARD snaked left and right of the direct flight path with the help of the reaction control system (RCS) thrusters.

Another objective was to study communications possibilities during reentry and, in particular, to analyse blackout phenomena and their effects on radio links. Radio blackout was expected between 90 km and 42 km altitude (actual: 90-43 km) as ionisation of the super-heated atmosphere interfered with signals. As soon as ARD reached 200 km, it was in telemetry contact with two US Air Force KC-135 aircraft.



*ARD vehicle architecture. (ESA/D. Ducros)*

*Main image: ARD integrated at Aerospatiale, Bordeaux. The heatshield included samples of new materials. Inset: post-flight measurements showed that the main shield was eroded by only 0.1-0.3 mm.*

The automatic parachute deployment sequence began at 87 min 56 s at 13.89 km above the Pacific Ocean. In order to avoid tearing the parachutes, the deployment sequence did not begin until the speed fell below Mach 0.7; maximum allowable dynamic pressure was 5000 Pa. The 91 cm-diameter extraction parachute was ejected by a mortar from under the back cover; this then extracted a 5.80 m drogue. That was jettisoned 78 s later at 6.7 km altitude, and a set of three 22.9 m-diameter main parachutes was released. They were reefed and opened in three steps in order to avoid over-stressing the system. They slowed the descent rate to 20 km/h at impact (7.3 *g*) at 134.0°E/3.90°N, south-east of Hawaii and north-east of the French Marquesa Islands. After landing, these parachutes were separated and two balloons inflated to ensure upright flotation.

Analysis of the telemetry received at the ARD Control Centre in Toulouse allowed the capsule's location to be determined within 1500 m. The French naval recovery ship approached within 100 m and then stood off for 6 h so that the capsule's interior could cool below 47°C, the explosive temperature for the remaining RCS hydrazine. The ship delivered ARD to Papeete in Tahiti, from where it was transported by a commercial ship to Europe and returned to Aerospatiale in Bordeaux for inspection and testing.

*Vehicle configuration:* conical capsule (70%-scale of Apollo Command Module), height 2.04 m, base diameter 2.80 m. Four main elements creating air- and water-tight pressurised structure: bulkhead structure with heatshield; conical section carrying RCS and internal secondary structure; secondary structure holding electrical equipment; back cover protecting descent & recovery systems. All structural elements made of mechanical-fastened aluminium alloy parts.

*Thermal protection:* heatshield exposed to 2000°C/1000 kW/m$^2$, conical surface to 1000°C/90-125 kW/m$^2$. Internal temperature within 40°C. 600 kg heatshield composed of 93 Aleastrasil tiles (randomly-oriented silica fibres impregnated with phenolic resin) arranged as one central tile and six circumferential rings. Conical surface coated with Norcoat 622-50FI (cork powder and phenolic resin). Samples of new materials tested: four Ceramic Matrix Composite heatshield tiles and two Flexible External Insulation panels on conical surface.

*Control:* automatic navigation, guidance and control system

ARD recovery from the Pacific Ocean.

Installation of ARD on its Ariane adapter in the final assembly building at the launch site. The combination was then hoisted on to the launch vehicle. (ESA/CNES/CSG)

consisted of Global Positioning System (GPS) receiver, inertial navigation system, computer, data bus and power supply & distribution system, and RCS. RCS was derived from Ariane-5's attitude control system, using seven 400 N thrusters (3 pitch, 2 roll, 2 yaw) drawing on hydrazine carried in two 58-litre tanks pressurised by nitrogen.

*Power system:* two 40 Ah NiCd Spot-4-type batteries.

*Communications:* >200 parameters recorded during flight and transmitted to TDRS and USAF aircraft at up to 250 kbit/s during descent below 200 km: 121 temperature channels, 38 pressure, 14 accelerometer and gyro, 8 reflectometer, 5 force measurement, 1 acoustic and functional parameters such as mission sequences.