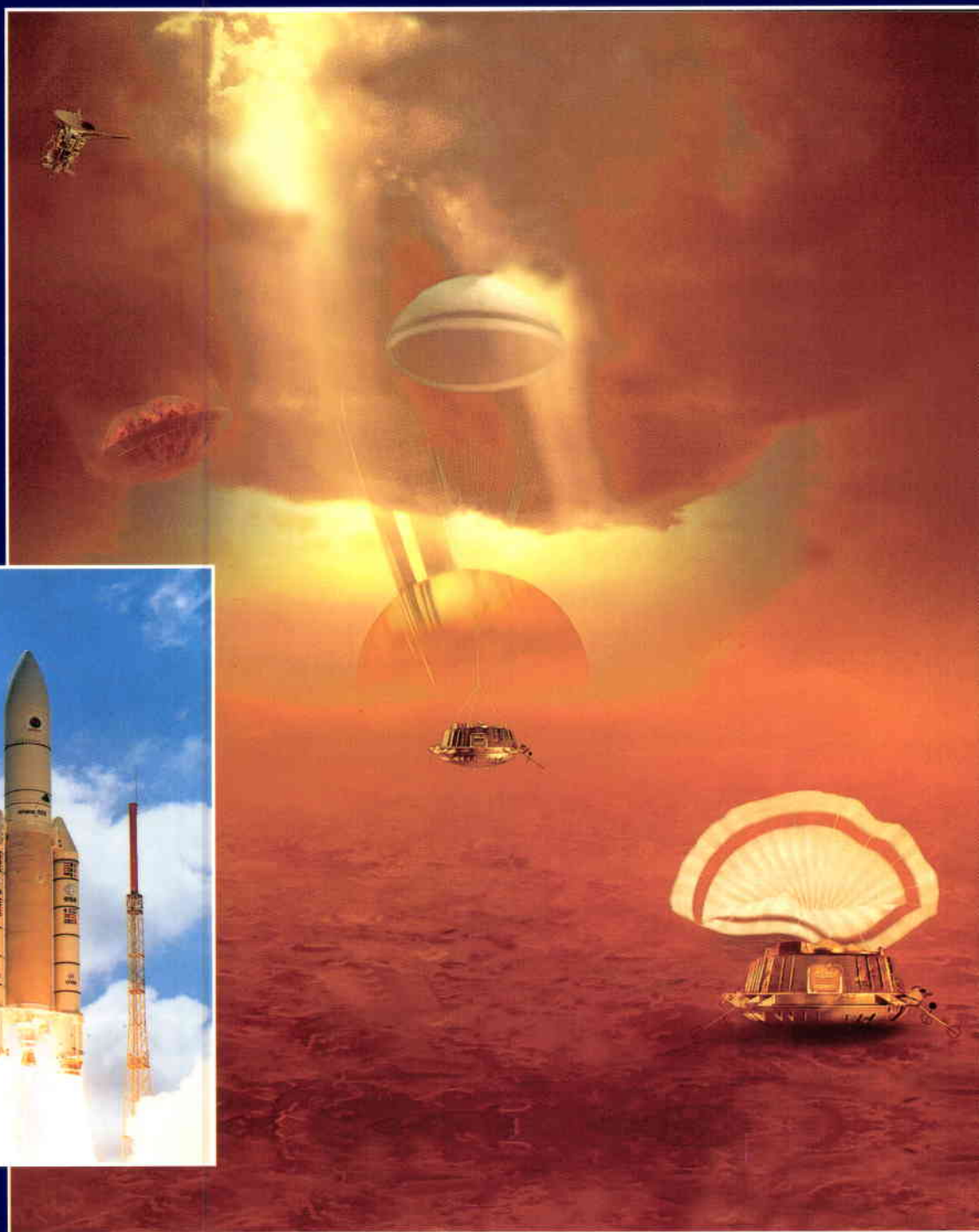




esa

bulletin

number 92 - november 1997





european space agency

The European Space Agency was formed out of, and took over the rights and obligations of, the two earlier European Space Organisations: the European Space Research Organisation (ESRO) and the European Organisation for the Development and Construction of Space Vehicle Launchers (ELDO). The Member States are Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Norway, Spain, Sweden, Switzerland and the United Kingdom. Canada is a Cooperating State.

In the words of the Convention: The purpose of the Agency shall be to provide for and to promote, for exclusively peaceful purposes, co-operation among European States in space research and technology and their space applications, with a view to their being used for scientific purposes and for operational space applications systems.

- (a) by elaborating and implementing a long-term European space policy, by recommending space objectives to the Member States, and by concerting the policies of the Member States with respect to other national and international organisations and institutions;
- (b) by elaborating and implementing activities and programmes in the space field;
- (c) by co-ordinating the European space programme and national programmes, and by integrating the latter progressively and as completely as possible into the European space programme, in particular as regards the development of applications satellites;
- (d) by elaborating and implementing the industrial policy appropriate to its programme and by recommending a coherent industrial policy to the Member States.

The Agency is directed by a Council composed of representatives of Member States. The Director General is the chief executive of the Agency and its legal representative.

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Chairman of the Council: H. Parr

Director General: A. Rodotà

agence spatiale européenne

L'Agence Spatiale Européenne est issue des deux Organisations spatiales européennes qui l'ont précédée — l'Organisation européenne de recherches spatiales (CERS) et l'Organisation européenne pour la mise au point et la construction de lanceurs d'engins spatiaux (CECLES) — dont elle a repris les droits et obligations. Les Etats membres en sont: l'Allemagne, l'Autriche, la Belgique, le Danemark, l'Espagne, la Finlande, la France, l'Irlande, l'Italie, la Norvège, les Pays-Bas, le Royaume-Uni, la Suède et la Suisse. Le Canada bénéficie d'un statut d'Etat coopérant.

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ESRIN, Frascati, Italie

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Directeur général: A. Rodotà

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Logica in Space

Logica is proud to be associated with many space science programmes, including:

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Giotto	mission control and data processing software, onboard data compression
Hipparcos	onboard software, end-to-end mission simulator, mission control and data processing software
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Ulysses	spacecraft control software, data processing
Comptel	data processing
Rosetta	autonomy studies
XMM	mission control and science operations software

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Payload Interface Unit



Antenna Pointing Electronic



Remote Terminal Unit



BPSK Modulator



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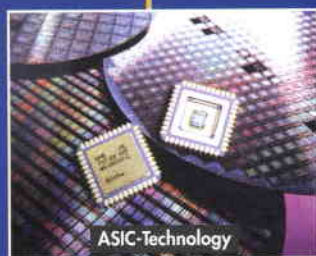
- On Board Data Handling
- Base Band Processing
- Antenna Pointing and Control System

▼ Radiofrequency Equipment:

- TTC S-Band Digital Transponder
- L-Band Transmitter
- BPSK/QPSK Modulators
- Filters, Diplexers, Multiplexers, etc.

▼ Systems Engineering:

- On-Board Processing OBP/ Multimedia
- Communications Network for air navigation (GNSS)
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ASIC-Technology



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Mating of the upper payload composite, consisting of Maqsat-H and Teamsat, with its flight adaptor in the Final Assembly Building in Kourou, French Guiana



Speltra/upper stage separation as seen by Teamsat



Lift-off of the second Ariane-5 qualification flight (V502), on 30 October 1997



Ariane-502 on the pad, shortly before launch

The Ariane-502 Success: A Demonstration of Europe's Commitment

The Launch Readiness Review for flight 502, held at the Guiana Space Centre, in Kourou, on 27 and 28 October had conducted a detailed analysis of the status of Europe's new-generation Ariane 502 launcher, its payload and all of the ground facilities, including the launch-base and down-range stations that would track the flight, and had declared them ready for the launch. The Director Generals of ESA and CNES accordingly authorised the start of the countdown for the 30 October lift-off, and the launcher itself was rolled out from the Final Assembly Building on the morning of 29 October.

As just reward for 16 months of intense effort by the ESA and CNES Teams, the second Ariane qualification flight, V502, took place on 30 October.

Lift-off occurred at 10h43 local time (01.43 p.m. GMT), 7 seconds after ignition of the main-stage Vulcain engine. Ariane-5's two solid-propellant boosters also powered the launcher during the first part of its flight, before their separation from the main stage. The fairing that protects the payloads during the ascent phase was jettisoned 3 minutes after lift-off.

27 minutes into the flight, the Maqsat-H and Maqsat-B platforms, carrying instruments to analyse the launcher's flight behaviour, and the Teamsat technology satellite were injected into orbit.

A preliminary analysis of the Ariane 502 flight data immediately after launch confirmed that all propulsion systems — the two solid boosters, the main cryogenic stage and the storable-propellant stage — had functioned correctly, as too did the launcher's software, guidance, attitude control and electrical systems. A disturbance in the movement of the main cryogenic stage, the source of which is still under investigation, resulted in a lower than expected orbit for Teamsat, which fortunately did not adversely affect the execution of the payload's experiments.

Commenting in Kourou on the results of this second qualification flight of Ariane-5, Antonio Rodotà, ESA's Director General, voicing his first thoughts and those of all of the ESA and CNES staff who had worked so hard to achieve this goal after the intense disappointment of the first flight, said: "...*This is another good example of what European cooperation can do!... All of us who have consistently believed in Ariane have today witnessed the start of a new success story.....*"

First indications are that the Teamsat (Technology, science and Education experiments Added to Maqsat) payload has functioned well. Its five experiments were proposed and delivered for integration in record time — just 7 months — by a number of European Universities working under the coordination of ESTEC's Automation and Informatics Department. The spacecraft itself was built using spare parts from other satellites, and technicians and engineers at ESTEC devoted many hours to helping the youngsters in its realisation. The unique picture shown here was taken by Teamsat's Visual Telemetry System (VTS) of three cameras designed to acquire images of critical operations. It shows the Ariane-5 Speltra/upper-stage composite lagging behind 64 seconds after separation at an altitude of 600 km, with Africa in the background.

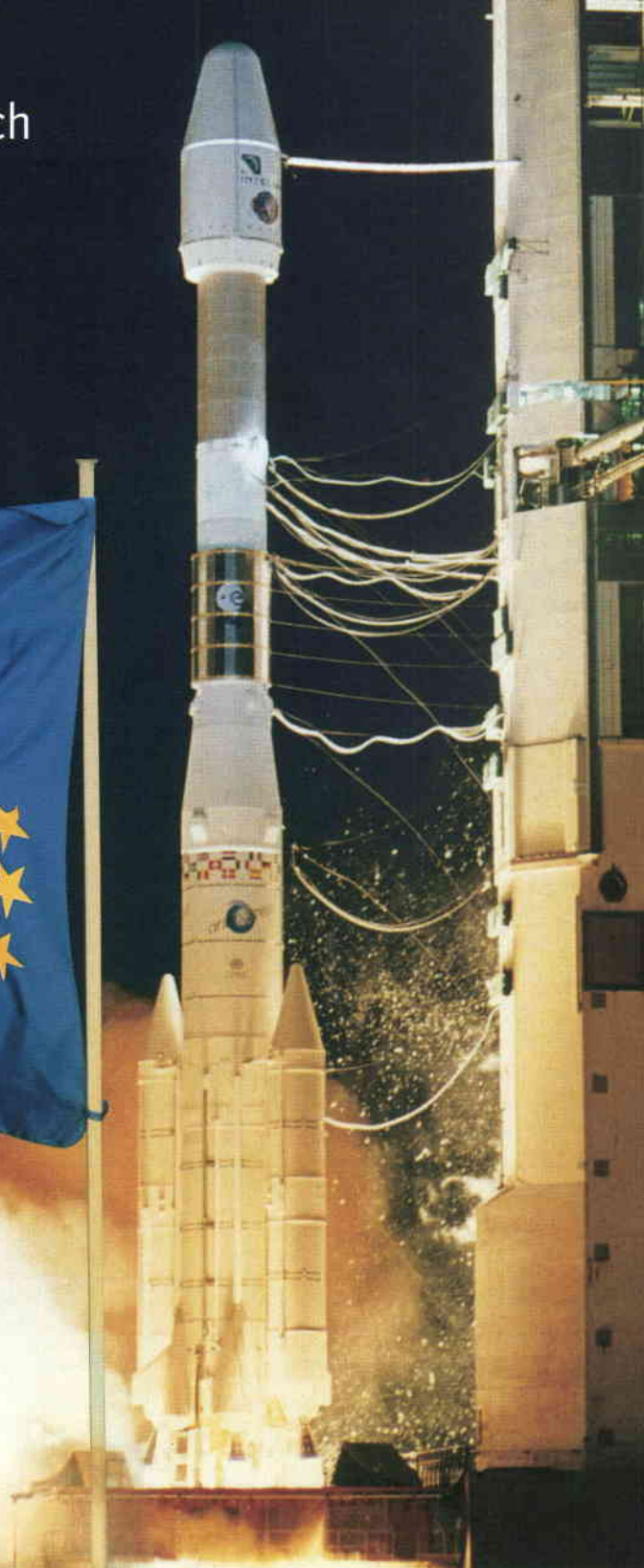
The third Ariane-5 qualification flight, under ESA and CNES responsibility, is scheduled for Spring 1998. Commercial Ariane-5 flights, which will be managed by Arianespace, will then begin with the fourth launch, currently planned for the second half of 1998.

The successful achievement of this major milestone in the Ariane-5 development programme is the result of the dedication and hard work of the 6500 people who have been involved in various capacities in the development of Europe's new launcher over the past ten years!

100th Ariane Launch



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The Ariane-5 Evolution Programme

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Ariane-5 Evolution: the rationale

To consolidate its success, Ariane must be continually adapted to the demands of the commercial market. As that market consists mainly of communication satellites, it is the trend in the mass of those satellites that will determine the future performance requirements for the launcher. The three decisive factors are therefore:

- the continuing increase in the mass of communication satellites
- the need to preserve systematically Ariane-5's ability to place dual payloads into Geostationary Transfer Orbit (GTO)
- the arrival in the marketplace of competitors offering attractive performance, such as McDonnell's Delta-III and Lockheed Martin's Atlas-2AR.

Experience with the previous versions of Ariane shows that systematic development is vital to ensure the launcher's steady adaptation to evolving user requirements. In the case of Ariane-5, a first evolution of the launcher was sanctioned by the Council Meeting at Ministerial Level in Granada in 1992. Preliminary studies were therefore conducted to establish a basis for the so-called 'Ariane-5 Evolution Programme', followed by an appropriate preparatory programme. The Ariane-5 Evolution Programme was formally accepted at the next Council Meeting at Ministerial Level, in Toulouse last October.

Several industrial studies that have looked at future use of the geostationary orbit (Euroconsult survey for ESA, Arianespace market research, etc.) have confirmed the trend towards heavier satellites. The introduction of new telecommunications services, the longer operational lifetimes of the new generations of satellites (15 to 18 years), and the growth in the number of transponders per spacecraft are all contributing to an across-the-board increase in satellite mass.

By the beginning of the 21st Century, the great majority of telecommunications satellite

suppliers are expected to be delivering platforms for launch into GTO with masses of 3500 to 3700 kg. Consequently, an increase in performance from 5970 to 7400 kg in GTO is the primary objective of the Ariane-5 Evolution Programme.

This increased performance to GTO implies a corresponding increase in launch capability for other orbits. In this context, Europe has already confirmed Ariane-5's role for low Earth transfer orbit missions to the International Space Station.

Programme content

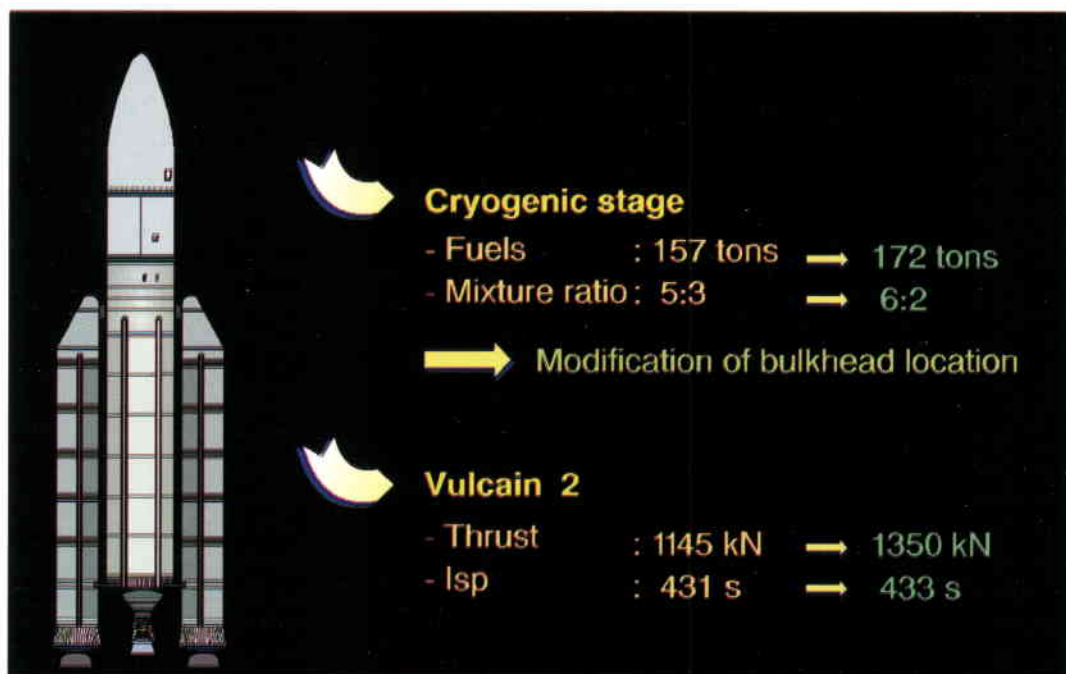
The Ariane-5E launcher is a close derivative of the initial Ariane-5 and retains the same general architecture:

- A lower composite, which is the same for all missions, provides the bulk of the velocity and altitude required to place payloads in orbit. It consists of a cryogenic main stage and two solid boosters.
- An upper composite provides for the remainder of the velocity and altitude gains required to reach the desired orbit and, once that orbit has been reached, to inject the satellite or satellites at the appropriate velocity and with the appropriate attitude. The configuration therefore varies depending on the mission to be carried out: single- or dual-launch, intended orbit, payload mass, etc.

The main configurations are designed for:

- *the dual launch of satellites into geostationary transfer orbit*: the upper composite consists of a storable propellant stage, a vehicle equipment bay, a Speltra or Sylda-5, and a fairing
- *the launch of Earth-observation satellites into Sun-synchronous orbit (generally single launches)*: the configuration is the same except for the dual-launch-bearing structure, which is not needed in most cases.

Figure 1. Modifications to cryogenic main stage



ARIANE-5

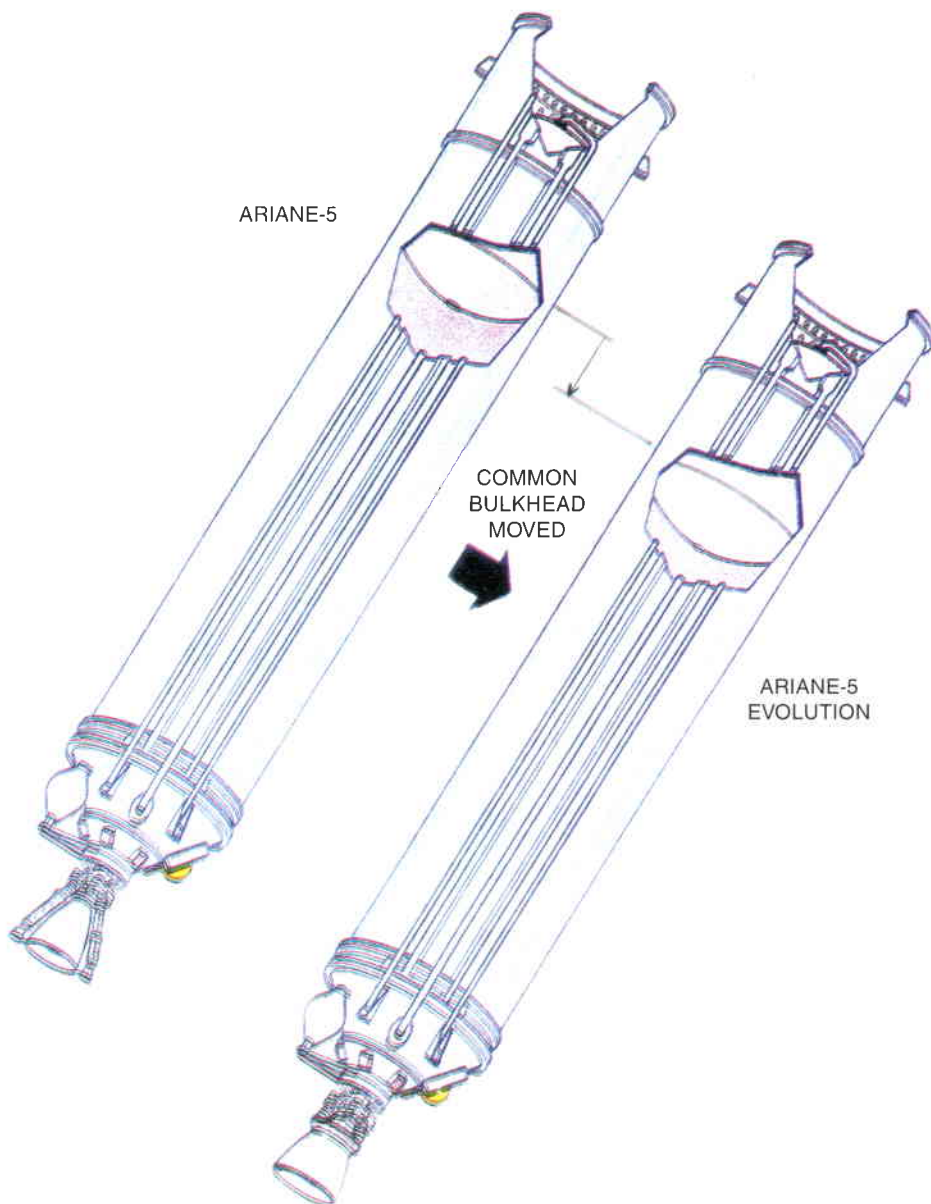


Figure 2. The modified cryogenic tanks

– the launch of payloads into low Earth orbit: the options are either to use the storable propellant stage with a small propellant load (the normal performance exceeding requirements), or not to use the stage at all if the payload has its own propulsion unit; as with the Sun-synchronous missions, the dual-launch bearing structure is not usually used.

The Ariane Evolution Programme involves the further development of several key elements of the launcher, as outlined below.

Cryogenic main stage and Vulcain engine

The cryogenic main stage of the Ariane-5E launcher is powered by a Vulcain-2 engine, the thrust of which is raised to 1350 kN and which carries 172 t of propellant.

The cryogenic main stage

The external dimensions of the stage are the same as for Ariane-5, with a height of 30 m and a diameter of 5.4 m. Its main elements are:

- the equipped insulated tank
- the other structures: thrust frame, forward and aft skirts
- the propulsion unit
- the electrical and pyrotechnic systems.

Equipped insulated tank

The Ariane-5E equipped insulated tank is characterised by a lowering of the common bulkhead by about 65 cm compared with the current design. This results in a 65 cm lengthening of the upper cylindrical section of the oxygen tank and a corresponding shortening of the first cylindrical section of the hydrogen tank.

A 16 t increase in oxygen mass compared with Ariane-5 makes it necessary to reinforce the common bulkhead, the lower cylindrical section of the oxygen tank, and the two upper cylindrical sections of the hydrogen tank.

The oxygen feed line will also be shortened, but its diameter will remain unchanged despite a 23% increase in the oxygen flow rate. The oxygen tank pressure will be raised by 0.5 bar to ensure a satisfactory supply to the Vulcain engine.

The hydrogen feed line and the other items forming part of the equipped insulated tank are compatible in principle with the propellant mass and thrust specified for the modified stage.

Simplified forming of the tank domes, by reducing the number of panels or the adoption of a spin-forming technique to allow single-piece manufacture, is currently under evaluation. Simplified welding and inspection procedures relying on increased automation are also foreseen. These two improvements should allow production costs for the cryogenic main stage to be reduced.

Thrust-frame, forward and aft skirts

Only the thrust-frame may have to be reinforced in view of the increase in Vulcain engine thrust. No changes are required to the other structures.

Pressurisation unit

The pressurisation unit must be capable of pressurising a larger oxygen tank. The helium

pressurisation system specified for Ariane-5 should be able to meet this increase in demand by using the existing margins, with no significant changes or redevelopment.

Electrical and pyrotechnic systems

The main effort with regard to the electrical systems will be on improvements aimed at reducing launcher production costs. One such action involves the bringing together of the electrical equipment common to the cryogenic main stage and the Vehicle Equipment Bay (VEB) (see later).

The Vulcain-2 engine

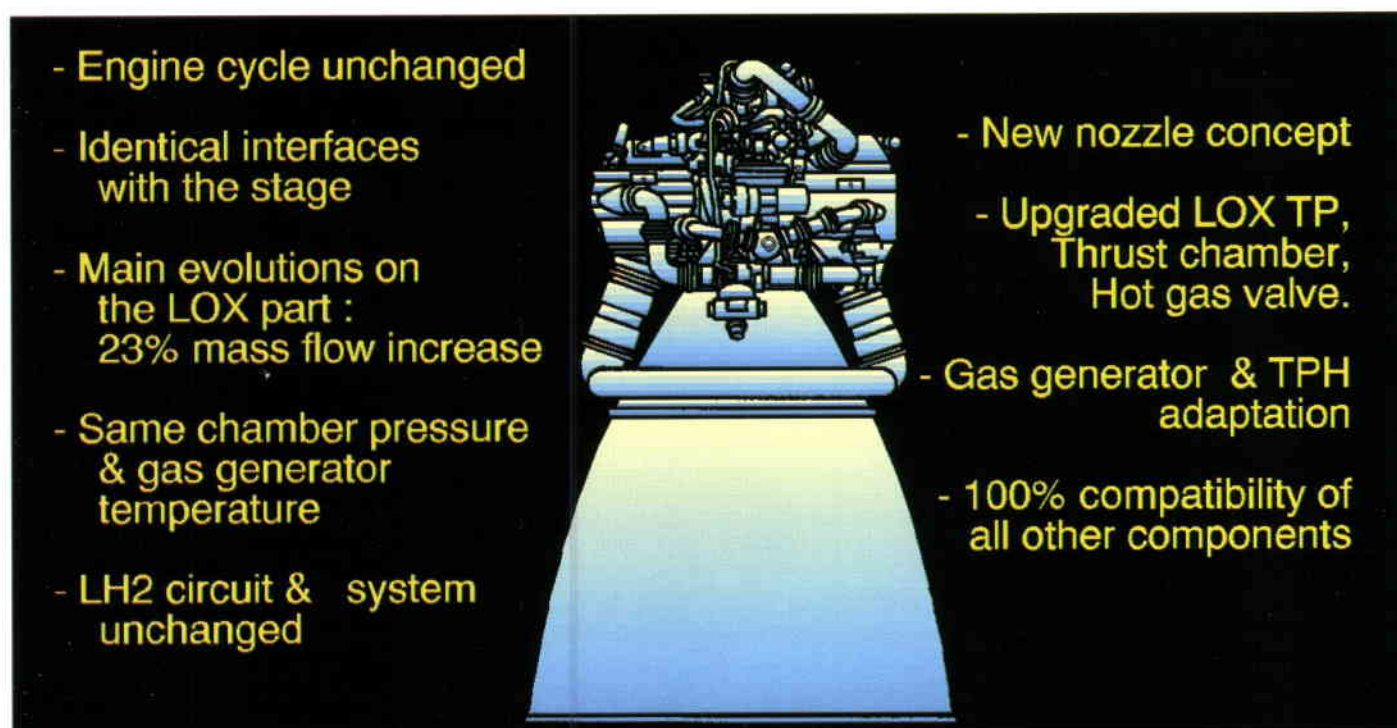
The increase in engine thrust from the current 1145 to 1350 kN is to be achieved mainly by stepping up the oxygen flow rate. The mixture ratio (between oxygen and hydrogen flow rates) is increased from 5:3 to 6:2.

The most important subsystems to undergo changes are the oxygen turbopump, which has to pressurise a 23% flow increase, the nozzle extension, and the combustion chamber, which has to accommodate the additional supply and cope with a higher mixture ratio.

The hydrogen turbopump as currently designed can cope with both the slight increase in flow for the enhanced version of the engine, and the pressure increase required to cool the combustion chamber more.

The gas generator must be capable of delivering a 20% increase in power to the turbopumps, which means its output must be

Figure 3. Improvements to the Vulcain engine



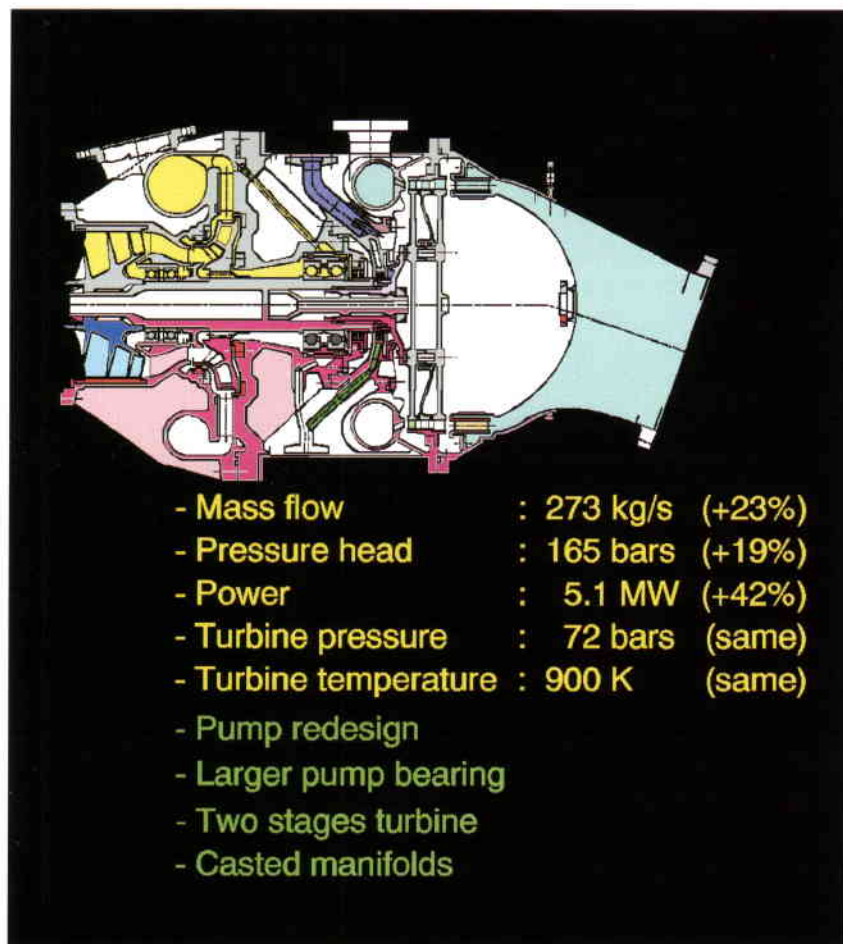


Figure 4. Improvements to the liquid oxygen (LOX) turbopump

increased. Its injector plate will be modified for this purpose.

Oxygen turbopump

The operating values for the modified oxygen turbopump are:

- a flow-rate increase of 23%
- an increase of 19% in output pressure
- a 42% increase in power consumption.

Its main features are:

Pump element

- new induction design which retains the Vulcain engine's good cavitation performance despite the flow-rate increase
- use of cast elements to reduce production costs, which is possible in view of the relatively modest set of changes to the existing pump
- unchanged external interfaces to limit the number of changes to the engine.

Turbine element

- two-stage turbine design to increase efficiency and reduce power demands on the gas generator
- again no change to external interfaces.

Dynamic shaft elements

- shaft remains as currently defined.

Combustion chamber

The operating values for the modified combustion chamber are:

- 23% increase in oxygen flow
- 6% increase in hydrogen flow
- consequent 20% total increase in flow-rate
- increase in mixture ratio from 5.3 to 6.2.

The resulting main characteristics are:

Chamber unit

- 10% increase in throat dimensions, enabling total flow to be stepped up and the increase in chamber pressure to be limited to 6%
- no change to external interfaces
- changes to the chamber's regenerative cooling circuit to make it compatible with the higher mixture ratio.

Injection unit

- simplification of the oxygen injection LOX

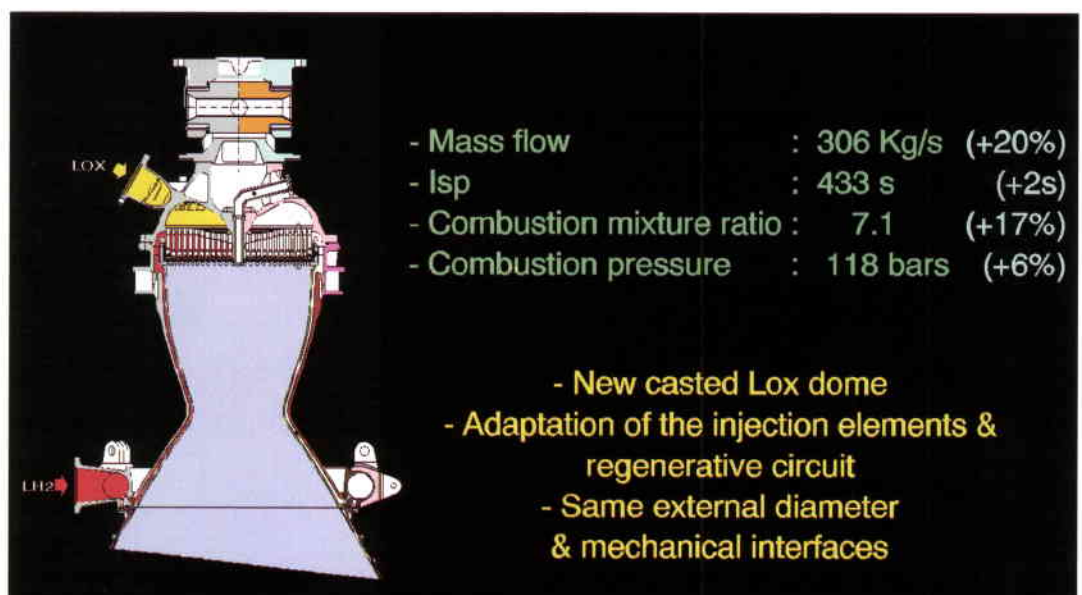


Figure 5. Modifications to the combustion chamber



Figure 6. The modified nozzle

dome to allow for the increase in oxygen flow, and partly to reduce chamber production costs

- again no change to external interfaces.

Nozzle extension

It is possible to complement the improvements in the Vulcain engine's direct thrust with improved nozzle design.

The Ariane-5E Vulcain engine nozzle extension is characterised by a significantly higher expansion ratio (up by 30%) and by the reintroduction of exhaust gases from the turbines. The increase in expansion ratio rate is possible thanks to a better understanding of actual demand in the real operating environment of the Vulcain engine. It makes for a significant improvement in gas expansion and hence in engine performance.

The reintroduction of turbine exhaust gases enables:

- a substantial area of the nozzle to be film-cooled, reducing the area that has to be cooled by hydrogen drawn from the main supply (dump cooling); as the amount of hydrogen tapped off for this purpose represents a loss in terms of engine performance, there is a corresponding increase in performance
- improved expansion of the turbine exhaust gases and the main flow as a result of reduced friction losses at the wall, leading to further improvements in engine performance.

This new nozzle, tagged the 'advanced divergent', has been the subject of technology demonstration activities prior to its final development.

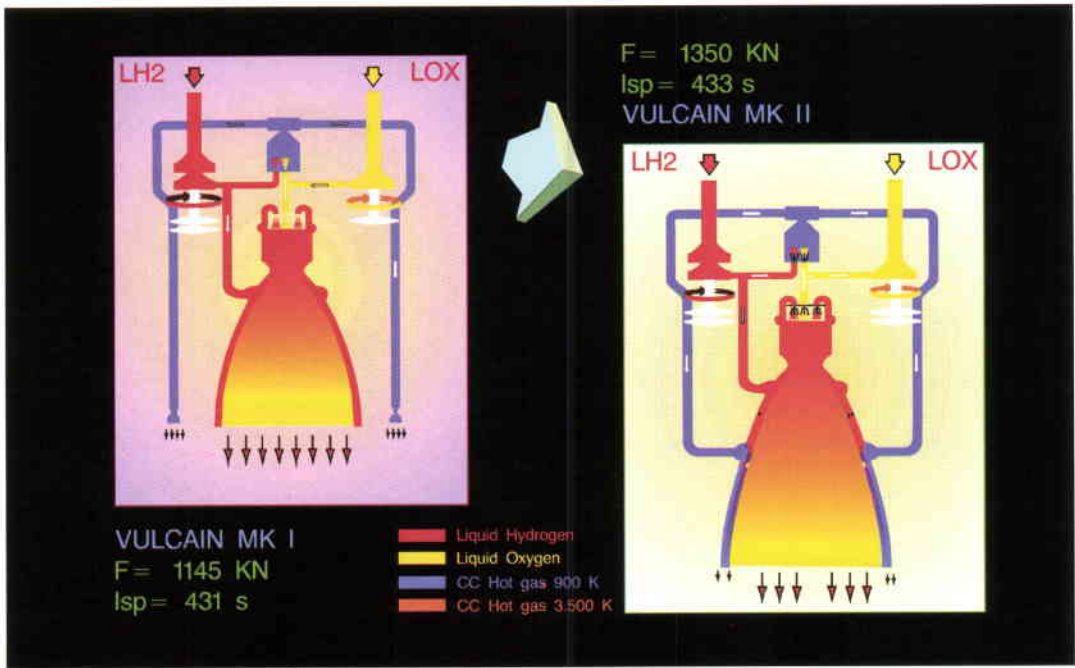


Figure 7. The re-injection of exhaust gases

Test facilities

The intended enhancement of the cryogenic stage is compatible with the existing ground facilities at the launch site in French Guiana in terms of stage testing and operational implementation. The test stands in Europe used for engine and subsystem testing will, however, have to be adapted to the new Vulcain engine specifications in that:

- Limited modifications will have to be made to the P5 engine stand at Lampholdshausen (D). Most of the changes needed relate to the increase in nozzle and consequently engine size (handling equipment, jet blast deflector, etc).
- The P5.9 oxygen turbopump stand in Germany will have to undergo more extensive modification to accommodate the increases in flow and output pressures.

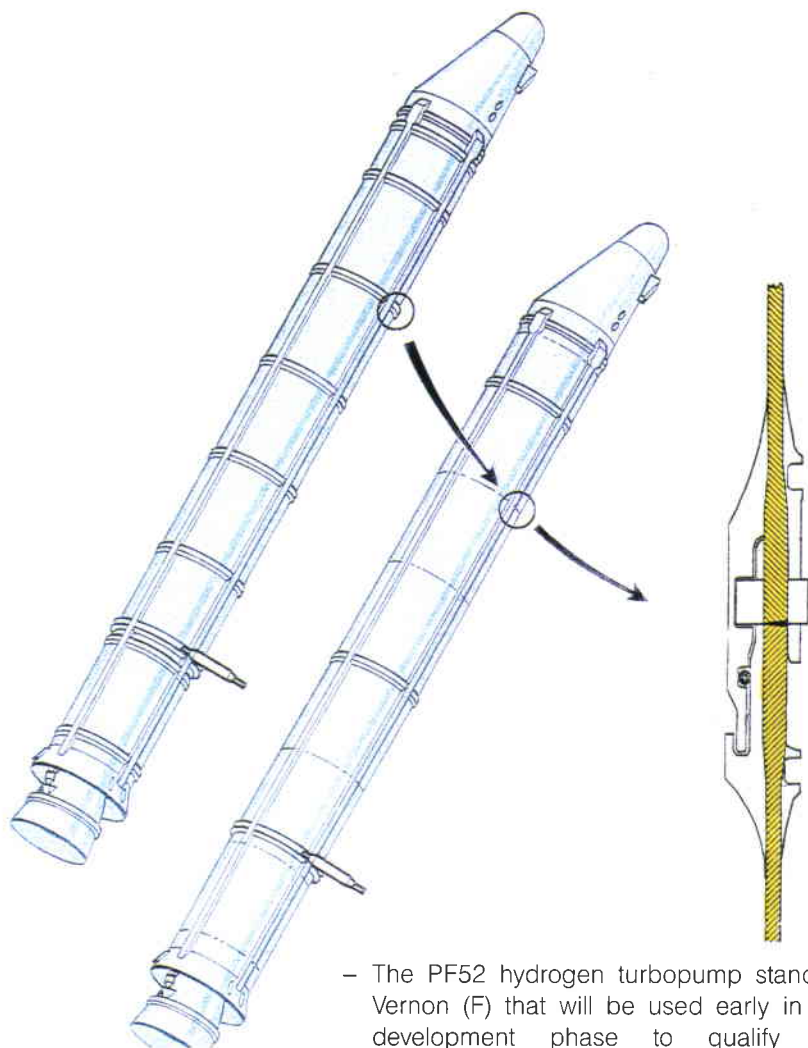


Figure 8. Welded cylindrical booster sections

Figure 9. Modifications to the Engine Propulsion Stage (EPS)

- The PF52 hydrogen turbopump stand at Vernon (F) that will be used early in the development phase to qualify the turbopump for the higher pressure range will have to be adapted for this purpose.

Solid-booster stage

The original solid-propellant booster consists of three main segments which are bolted together. The two lower S2 and S3 segments are similar and also composed of bolted cylindrical sections.

The main enhancement to the solid booster stage for Ariane-5E lies in the planned use of an improved technology for joining the cylindrical sections, with the present seals and bolted junctions being replaced by welding. Studies are currently underway to establish the weldability of the metallic material from which the cylindrical sections are made.

This upgrade is expected to provide:

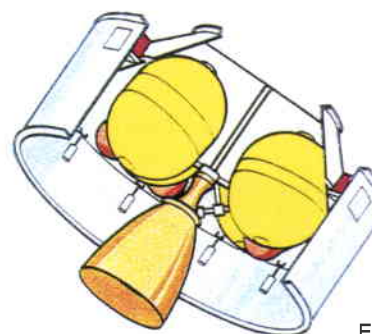
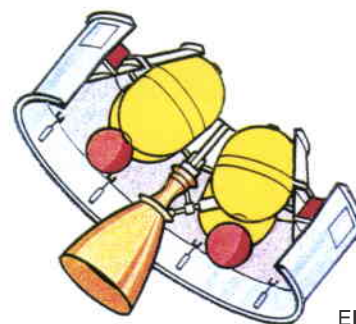
- increased performance due to the significant lightening of the booster structure (1.9 t of booster dry mass)
- greater reliability thanks to the simplicity of the welded joints
- significantly lower production costs.

Storable-propellant stage

Of the possible ways of easily increasing stage performance with a minimum of development risk, whilst retaining the same stage architecture and reliability, an increase in the propellant mass to 15 t has been selected. This in turn leads to an increase in both the size of the four cylindrical/spherical tanks and the height of the launcher's external structure.

The stage architecture will be based on a structure with a diameter of 4.55 m, which is between the present diameter of 3.94 m and the launcher's external diameter of 5.40 m. Consequently, the conical structure of the equipment bay will be shortened and reinforced and its external cylindrical structure will be lengthened.

38 kN of thrust will be extracted from the Aestus engine by adding a further row of



injectors to the current injector plate and by enlarging the overall dimensions of the engine accordingly. In this way it will be possible to retain the existing injectors and the current chamber pressure, and hence much of the experience acquired with existing hardware (particularly with regard to high-frequency stability) will still be valid.

A preliminary analysis suggests that chamber cooling should not be adversely affected by the increase in size.

The pressurisation unit will be modified by incorporating an additional pressurisation bottle and adapting equipment to accommodate the increased engine thrust.

Test facilities

The test facilities in Europe, primarily the engine and stage stands, will need to be adapted to cope with the increased flows required by the 38 kN engine.

Vehicle Equipment Bay

The VEB will have to be reinforced and adapted to cope with the increased volume and mass of the storable propellant stage, the exact modifications depending on the stage configuration ultimately chosen.

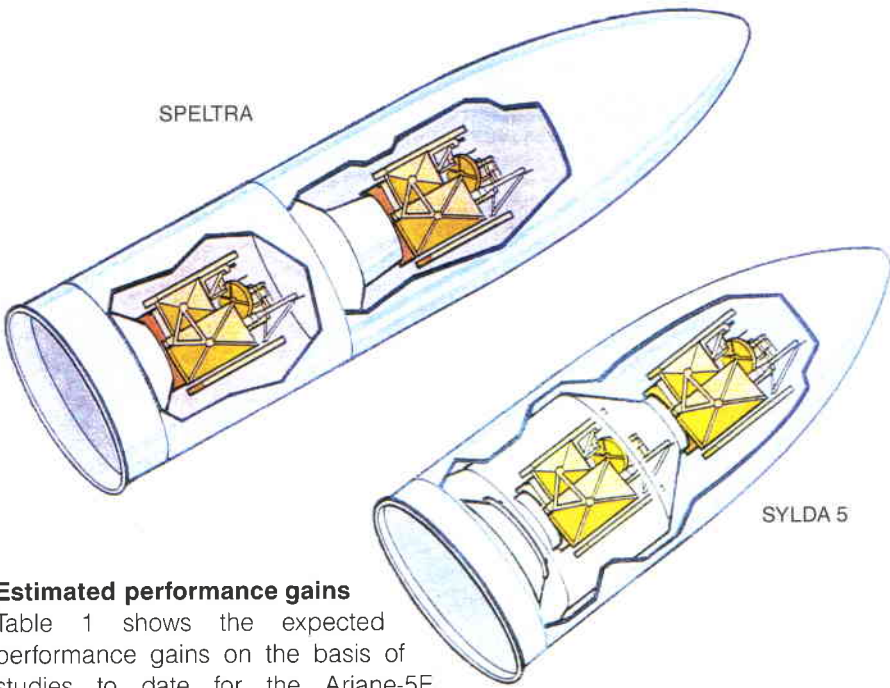
Various improvements aimed at reducing costs will be made to the VEB, most involving the simplification or grouping together of electrical equipment.

One such possibility is to group the switching units currently located between the equipment bay and the cryogenic main stage. Bringing them together in the equipment bay would allow the number of units, and hence production costs, to be reduced.

Ariane-5 dual-launch system

The dual-launch system (Sylda-5) proposed for Ariane-5E is a structure entirely within the fairing which can accommodate a satellite with a diameter of 4 m in the lower position. This represents ample capability in the short term given currently competing platforms and launchers, and it is still possible to launch satellites with diameters up to 4.57 m in the upper position.

The overall height of Sylda-5 is 5.08 m. Its estimated mass of between 400 and 500 kg (precise figure to be confirmed at the start of Ariane-5E development) represents a saving of at least 350 kg compared with the current Speltra. The fact that it is also both simpler and lighter will allow production costs to be reduced significantly.



Estimated performance gains

Table 1 shows the expected performance gains on the basis of studies to date for the Ariane-5E reference mission, namely a launch into Geostationary Transfer Orbit (GTO):

Figure 10. Modified dual-launch system

It can be seen that a 1500 kg increase in performance can be obtained without the EPS modification, which could be retained for a later upgraded version of Ariane-5E.

Ground and transport facilities

The integration and launch facilities in Kourou and the transport facilities for the launcher elements, which represented a significant investment for the Ariane-5 programme, can be reused for Ariane-5E without major change.

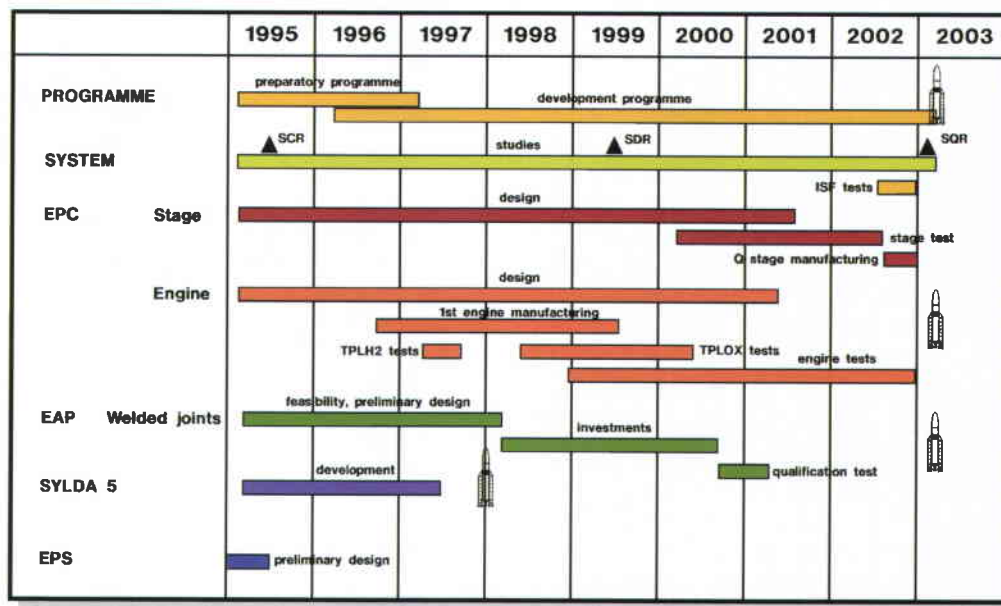
The launch trajectory will make it necessary to reopen the Libreville telemetry station, which is used for Ariane-4 but was not envisaged to be needed for Ariane-5.

Not only will the Ariane-5E cryogenic main stage have the same external dimensions as the current stage, but all of the interfaces now used for handling, transport, storage and

Table 1. Ariane-5E performance gains

Change	Increase in lift-capability to GTO	
	With EPS improvement	Without EPS improvement
Cryogenic main stage	1000 kg	1000 kg
Sylda-5	350 kg	350 kg
Solid booster stage	150 kg	150 kg
Storable propellant stage	300 kg	0 kg
Total	1800 kg	1500 kg

Figure 11. Launcher development planning



operation will also be retained. Only the Vulcain engine nozzle will call for special checks.

The modifications to the solid boosters will not affect either their transport or the associated ground operations in Kourou.

The only changes to the Vehicle Equipment Bay are those needed to adapt it to the possible modified storable-propellant stage version, which has no influence on the ground facilities.

The Sylda-5 structure will require only relatively minor adaptations as regards the handling of the new structure and the integration of payloads.

Schedule objectives

The aim is to have the Ariane-5 growth version operational in 2003 so as to be able to continue systematically performing dual GTO launches under attractive conditions. The steady evolution in performance needs makes it desirable, in as far as the launcher's design allows, to have a number of 'intermediate' versions available. This will allow the launcher's lift capability to be increased gradually as the growth version is developed. The development of Sylda-5 will allow the GTO lift capability to be increased by around 300 kg from the end of 1997, and the remaining gain will be achieved at the end of 2003. Due to the blocking of the modification of the EPS stage, the schedule has been limited to the preliminary design studies.

Economic objectives

Development costs

Development costs will have to be kept as low as possible. Consequently, the development effort has been limited to include only that work strictly necessary for the goals to be achieved efficiently and economically. It is particularly important that we capitalise on the experience gained, in order to ensure that European industry maintains an engineering capability in this field.

Recurrent production/launch costs

The already stiff competition between the various companies offering launch services on the open market is bound to become even tougher. The reduction of launch costs therefore has to be a major objective for the Ariane-5 Evolution Programme.

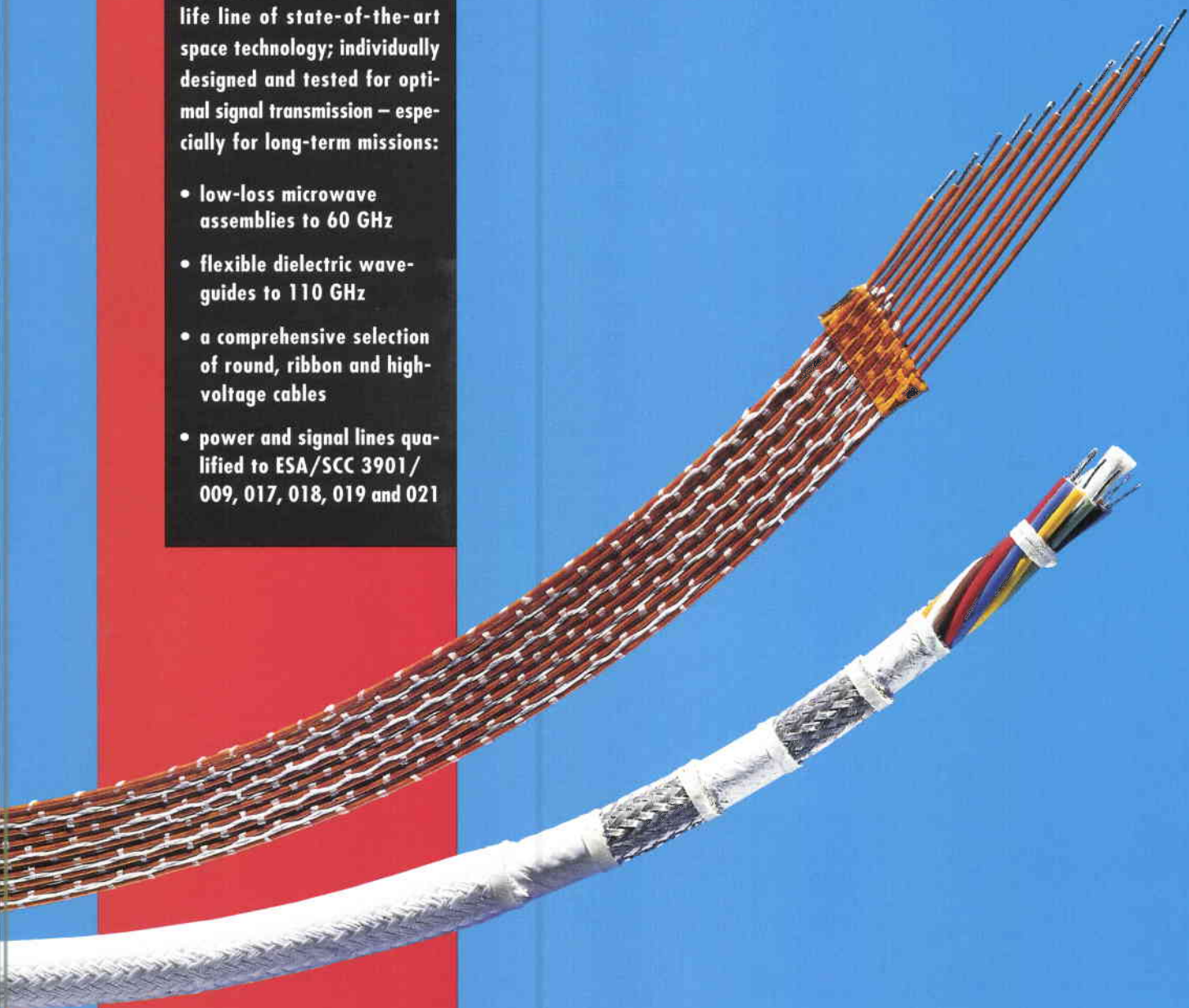
Conclusion

The Ariane-5 Evolution Programme has been agreed by the Ariane Launcher Programme Board as defined in the Programme Proposal, with the exception of the EPS modification, which has been frozen. The main objective is to achieve an increase of 1400 kg in performance for the GTO reference mission, and the target date for completion of the programme is 2003. The main modifications are now well-defined and all of the various contractors are already working hard to achieve both of these goals. There is an intermediate milestone in 1997 provided by the availability of Sylda-5, which will already provide a 350 kg increase in payload capability to GTO.

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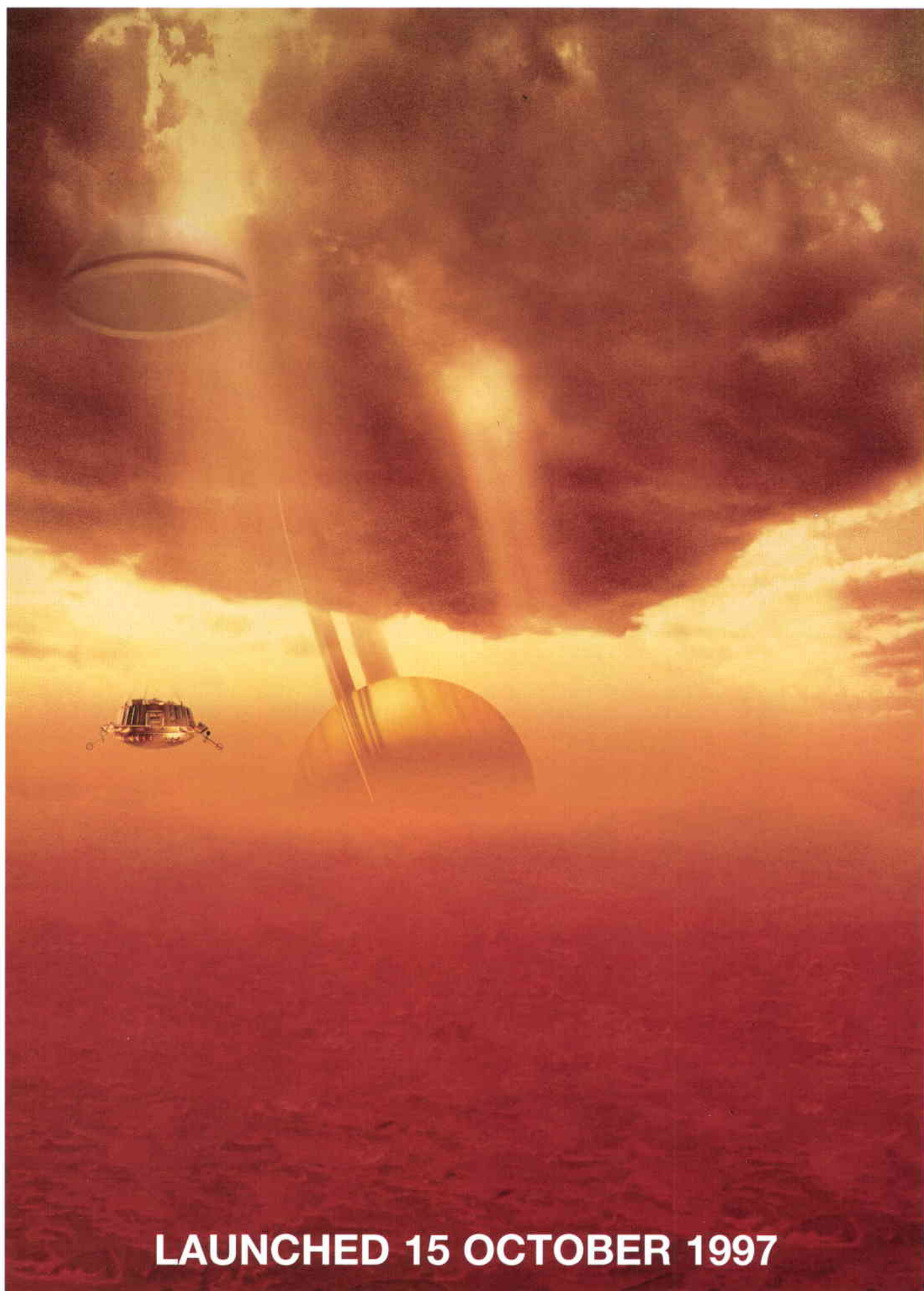


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The Huygens Probe: Science, Payload and Mission Overview*

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Introduction

Huygens is designed to study the atmosphere and surface of Titan, Saturn's largest moon, by conducting detailed in-situ measurements of the physical properties, chemical composition and dynamics of the atmosphere and local characterisation of the surface. It is a highly sophisticated robotic laboratory carrying six scientific instruments. Huygens is the element contributed by ESA to Cassini/Huygens, the joint NASA/ESA dual-craft mission to the Saturnian system. NASA has provided the Saturn Orbiter. The overall mission is named after the French/Italian astronomer Jean-Dominique Cassini, who discovered several Saturnian satellites and ring features (the Cassini division) in 1671-1685. The Probe is named after Dutch astronomer Christiaan Huygens, who discovered Titan in 1655.

The Huygens Probe is ESA's element of the joint Cassini/Huygens mission with NASA to the Saturnian system. Huygens will be carried on NASA's Cassini Orbiter to Saturn, where it will be released to enter the atmosphere of Titan, the planet's largest satellite. The Probe's primary scientific phase occurs during the 2-2.5 h parachute descent, when the six onboard instruments execute a complex series of measurements to study the atmosphere's chemical and physical properties. Measurements will also be conducted during the 3 min entry phase, and possibly on Titan's surface if Huygens survives impact. This article provides an overview of the mission and a concise description of the payload.

Launch occurred from Cape Canaveral, Florida aboard a Titan-4B/Centaur rocket on 15 October 1997 during the primary launch window. After an interplanetary voyage of 6.7 years, the spacecraft will arrive at Saturn in late June 2004, when a manoeuvre will place it in orbit around the planet. The Probe's mission will be executed in November 2004, at the end of the first of the many orbits around Saturn. Following the Huygens mission, the Orbiter will begin its intensive 4-year exploration of the Saturnian system.

The exploration of Titan is at the very heart of the Cassini/Huygens mission. The Orbiter will make repeated targeted close flybys of Titan, gathering data about the moon and making gravity-assisted orbit changes that will allow it to make a tour of the satellites, reconnoitre the magnetosphere and obtain views of Saturn's higher latitudes. During its 4-year nominal mission, Cassini will make detailed observations of Saturn's atmosphere, magnetosphere, rings, icy satellites and Titan. The detailed in-situ data set acquired by the Probe and the global data set from the Orbiter's tour will undoubtedly provide a unique wealth of information that will substantially increase our knowledge of Titan, a fascinating planet-sized moon shrouded by a thick, hazy and chemically active atmosphere.

The mission's development

The development of such a complex and ambitious venture between NASA and ESA required substantial scientific, technical and programmatic planning efforts over several years. Several scenarios for a mission to Saturn were studied within NASA from the late 1970s as the next natural step, after the Galileo orbiter/probe mission to Jupiter, in the detailed exploration of the giant planets.

The Cassini mission, in its present form, was originally proposed to ESA as a collaborative venture with NASA in response to a regular call for mission ideas released by ESA's Directorate of Scientific Programmes. The mission was proposed in November 1982 by a team of European and US scientists lead by D. Gautier and W. Ip. After an initial assessment, it was then subjected to a joint 1-year ESA/NASA assessment study starting in mid-1984. Very early in that study phase, the Titan Probe was identified as ESA's potential contribution, within its financial constraints and the technical capabilities of the European space industry. It was subsequently selected by ESA for a competitive Phase-A study in 1986, but the

* An extended version of this article can be found in *Huygens: Science, Payload and Mission*, ESA SP-1177, August 1997

start was delayed by a year to allow programmatic adjustment with NASA. The Phase-A study therefore ran from November 1987 to September 1988.

The Titan Probe was selected by ESA's Science Programme Committee in November 1988 as the first medium-size mission ('M1') of the Horizon 2000 long-term space science plan. During that process it was named Huygens, in honour of the discoverer of Titan. Within NASA, Cassini was part of the CRAF (Comet Rendezvous and Asteroid Flyby)/Cassini programme, which was approved in the 1989 budget.



Figure 1. The Cassini / Huygens spacecraft

CRAF was cancelled by NASA for budgetary reasons in January 1992 and Cassini was greatly restructured, leaving the modified Cassini-alone programme to be authorised in May 1992. As a result of the restructuring, the two articulated orbiter science platforms and the articulated dedicated Huygens antenna were deleted. The Orbiter instruments became body-mounted, but several instruments added their own articulation to temper the losses of the platforms. The Huygens receivers were directly interfaced with the Orbiter's main antenna. Huygens was essentially unhurt by the restructuring process.

ESA and NASA released a joint Announcement of Opportunity in October 1989 calling for investigations on the Probe and Orbiter,

respectively. Both payloads were selected in close coordination between the two agencies and with the European national agencies that provided funding for specific hardware contributions. The Probe and Orbiter payload selections were announced by ESA and NASA, respectively, in September and November 1990. In addition to hardware investigations, ESA and NASA respectively selected three and seven Interdisciplinary Scientist Investigations.

During the investigation selection process, the Italian Space Agency (ASI) initiated a bilateral collaboration with NASA that provided for significant augmentation of the Orbiter payload capabilities beyond what NASA alone could fund, in areas of prime interest to the Italian scientific community. This bilateral effort also included the provision by ASI of a major Orbiter element: the four-band (S, X, Ku, Ka) High-Gain Antenna (HGA).

During the Phase-A study, the need for using a gravity assist to inject the spacecraft towards Saturn was recognised. Three launch opportunities were identified that included a Jupiter flyby in addition to Venus and Earth flybys. Jupiter is required to reach Saturn in a reasonable time: 6-7 years, instead of 9-10 years. At the time of the joint CRAF/Cassini programme, Cassini was scheduled for launch during the second opportunity, in April 1996. After CRAF's cancellation, the possibility of accelerating the programme and launching in December 1995 was looked at, but the October 1997 launch opportunity was eventually selected as it was the only one of the three compatible with NASA's budget profile for developing the Cassini spacecraft.

Overview of the Cassini/Huygens mission

The Cassini mission is designed to explore the Saturnian system and all its elements: the planet and its atmosphere, rings, magnetosphere and a large number of its moons, namely Titan and the icy satellites. The mission will pay special attention to Titan, Saturn's largest moon and the Solar System's second largest after Jupiter's Ganymede. Cassini's broad scientific aims are to:

- determine the dynamical behaviour of Saturn's atmosphere
- determine the chemical composition, physical structure and energy balance of Titan's atmosphere
- observe the temporal and spatial variability of Titan's clouds and hazes
- characterise Titan's surface
- determine the structure, composition and geological history of Saturn's icy satellites
- study the structure of the rings and the

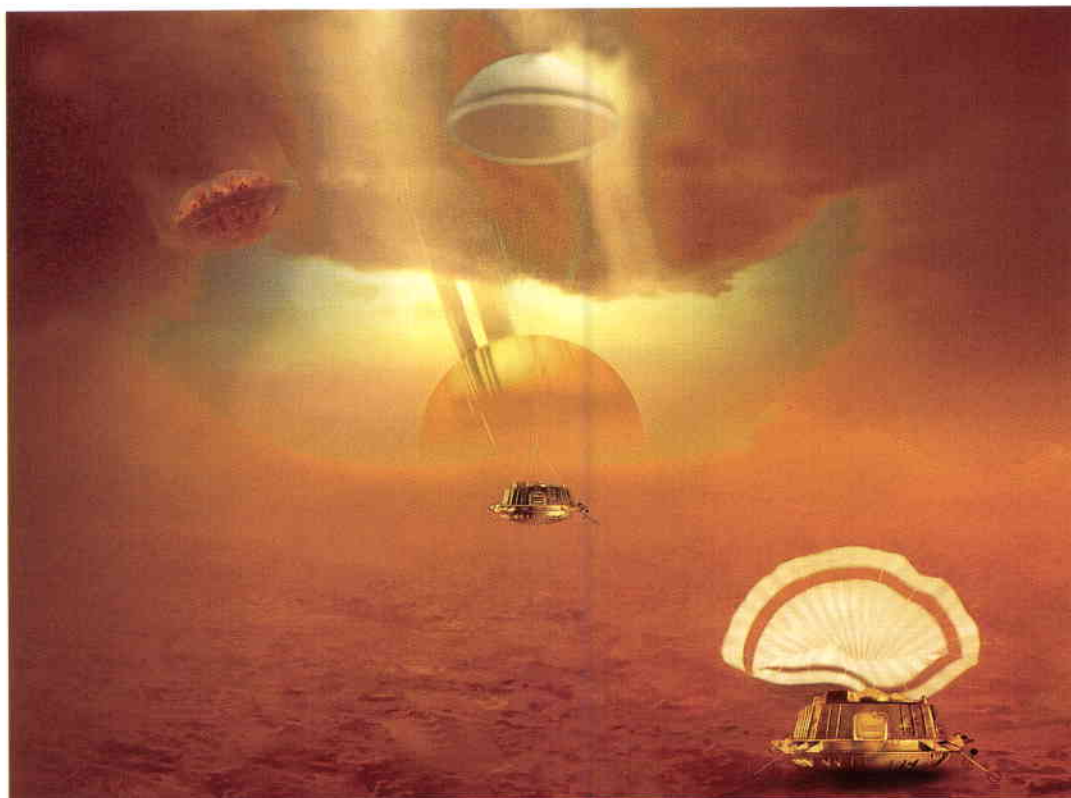


Figure 2. The Huygens Probe descent

- composition of the rings' material
- study the structure, chemical composition and global dynamics of Saturn's magnetosphere.

An important aspect of the Cassini mission is studying the interaction and interrelation of the system's elements. Studying the interrelation between the rings and the icy satellites, and the interaction of the satellites and of Titan's ionosphere with Saturn's magnetosphere is a key objective.

The Cassini/Huygens spacecraft (Figs. 1 & 2) was launched at 08:43 UT on 15 October 1997 by a Titan-4B/Centaur from Cape Canaveral Air Station in Florida. At a launch mass of 5548 kg, it is too heavy for direct injection to Saturn. Instead, it requires gravity assists from several planets: Venus (April 1998 and June 1999), Earth (August 1999) and Jupiter (December 2000). This launch opportunity allows Saturn to be reached in 6.7 years. The primary window extended from 6 October to 4 November, with contingency days available to 15 November. There were later opportunities (which add 2 years to the total flight time to Saturn because they do not include a Jupiter flyby) in December 1997 and March 1999, but they were less favourable from the launch performance and science points of view. This is particularly true for the ring science as the solar and Earth-viewing phase angle of the rings will be much less favourable in 2008-2012 than in 2004-2008. The maximum ring opening angle occurs in 2002.

Cassini/Huygens will arrive in the vicinity of Saturn in late June 2004. The date has been calculated to allow a flyby of distant moon Phoebe during the approach phase to Saturn. The most critical phase of the mission after launch is Saturn Orbit Insertion (SOI), on 1 July 2004. Not only is it a crucial manoeuvre, but also a period of unique Orbiter science activity as, at that time, the spacecraft is as close as it ever will be to the planet (at $0.3 R_s$ about 2 h before and 2 h after ring-plane crossing). Ring-plane crossing occurs in the gap between the F and G rings at a distance of about $2.66 R_s$. The SOI part of the trajectory provides a unique observation geometry for the rings.

The Huygens Probe is carried to Titan attached to the Saturn Orbiter and released from the Orbiter on 6 November 2004 after SOI at the end of the initial orbit around Saturn, nominally 22 days before Titan encounter (Fig. 3). Shortly (typically two days) after Probe release, the Orbiter will perform a deflection manoeuvre to set up the radio link geometry for the Probe's descent phase. This manoeuvre will also set up the initial conditions for the satellite tour after completion of the Probe mission.

Huygens' encounter with Titan is planned for 27 November 2004. The celestial mechanics do not allow much freedom in the arrival date at Saturn, but Huygens' Titan encounter date, dictated by the duration of the initial orbit around Saturn, is adjustable by multiples of 16 days, corresponding to Titan's 15.95 day orbital period around its parent.

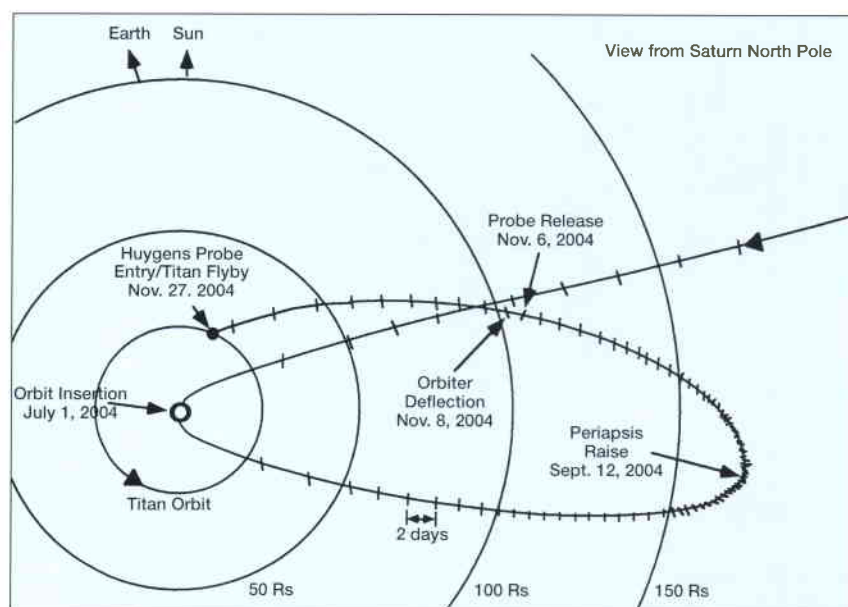


Figure 3. The Huygens release orbit. Huygens will be released from the Orbiter at the end of the first revolution around Saturn, with the second orbit as a backup possibility

Huygens scientific objectives

The scientific objectives of the Cassini/Huygens mission at Titan are to:

- determine atmospheric composition
- investigate energy sources for atmospheric chemistry
- study aerosol properties and cloud physics
- measure winds and global temperatures
- determine properties of the surface and infer internal structure
- investigate the upper atmosphere and ionosphere.

Huygens' goals are to make a detailed in-situ study of Titan's atmosphere and to characterise the satellite's surface along the descent ground track and near the landing site. Following the entry phase, at the start of the descent phase and after deployment of the parachute at about 165 km altitude, all instruments will have direct access to the atmosphere. The objectives are to make detailed in-situ measurements of atmospheric structure, composition and dynamics. Images and other remote-sensing measurements of the surface will also be made during the atmosphere descent. After a descent of about 137 min, the Probe will impact the surface at 5-6 m/s. As it is hoped that Huygens will survive after impact for at least a few minutes, the payload includes the capability for making in-situ measurements for a direct characterisation of the landing-site surface. If everything functions nominally, the Probe batteries can provide 30-45 min of electrical energy for an extended surface science phase that would be the bonus of the mission. The current mission scenario foresees the Orbiter listening to the Probe for a full 3 h, which includes at least a 30 min surface phase, as the maximum descent time is expected to be 2.5 h. A surface phase of only a few minutes would allow a quick

characterisation of the state and composition of the landing site. An extended surface phase would allow a detailed analysis of a surface sample and meteorological studies of the surface weathering and atmosphere dynamics.

Titan

General characteristics

Titan is the second largest moon in the Solar System and it is the only one with a thick atmosphere (Table 1). That atmosphere was discovered in 1907 by Spanish astronomer José Comas Solá, who observed disc edge darkening features and suggested that they were due to an atmosphere, although its existence was not confirmed until 1944 when Gerard Kuiper discovered gaseous methane spectroscopically. Molecular nitrogen is the major constituent, with the surface pressure 1.5 bar (compared to Earth's 1 bar). Until the mid-1970s, methane was believed to be the major constituent, but the Voyager-1 measurements in November 1980 replaced it with nitrogen, as was already suspected from late 1970s models. The presence of nitrogen makes Titan's atmosphere more similar to Earth's than any other Solar System body. However, it is much colder: the surface temperature is 94 K and the tropopause temperature is about 70 K at an altitude of 45 km. Other major constituents are CH₄ (a few %) and H₂ (0.2%). It is speculated that argon could also be present in quantities up to 6%. The presence of methane makes Titan's atmosphere most interesting.

The photodissociation of CH₄ and N₂ in Titan's atmosphere, driven by solar UV radiation, cosmic rays and precipitating energetic particles from Saturn's magnetosphere, gives rise to a complex organic chemistry. Titan orbits Saturn at 20.3 Rs, which occasionally brings it outside the large Kronian magneto-

Table 1. Physical properties of Titan

Surface radius	2575±0.5 km
Mass	1.346x10 ²³ kg (2.2% M _{Earth})
GM	8978.1 km ³ /s ²
Surface gravity	1.345 m/s ²
Mean density	1.881 g/cm ³
Distance from Saturn	1.226x10 ⁶ km (20.3 R _S)
Orbital period	15.95 d
Rotation period	15.95 d
Surface temperature	94 K
Surface pressure	1496±20 mbar

sphere when solar-wind pressure pushes the magnetopause inside the orbit. Most of the time, however, Titan is inside Saturn's magnetosphere, which underlines the importance of the energetic electrons as an energy source for its upper-atmosphere photochemistry. As a result of this complex photochemistry, the atmosphere also contains ethane, acetylene and more complex hydrocarbon molecules. Chemical reactions in the continuously evolving atmosphere provide possible analogues for the prebiotic chemistry that was at work within the atmosphere of the primitive Earth a few thousand million years ago, before the appearance of life. Titan's atmosphere is too cold for life to evolve in it, but the mission does offer the opportunity to study prebiotic chemistry on a planetary scale (see T. Owen's article in this issue).

The nature of the surface is Titan's main mystery. Like Earth, it could be partially covered by lakes or even oceans, but in this case a mixture of liquid methane and ethane. However, it may be a dry surface, with underground liquid-methane reservoirs continuously resupplying the atmosphere's gaseous methane.

Atmospheric thermal profile

The most reliable 'engineering' model of Titan's atmosphere was established in 1986 by Lellouch and Hunten during the Phase-A study (Fig. 4). Subsequently, an improved model was established by Yelle. This did not disagree significantly in the altitude range of prime concern, so the original was retained as the reference model for designing the Huygens entry heat shield and the parachute system.

Upper-atmosphere composition

The possible presence of argon in Titan's atmosphere was a major design constraint for the heat shield, as it would significantly contribute to the radiative heat flux during entry. The shield was thus designed to be compatible with the maximum argon content identified by the Lellouch-Hunten model (21%). The upper limit was subsequently reduced to 14% and then to 6%, to the growing satisfaction of the heat shield designers as their performance margin increased.

Wind model

The presence of a zonal wind will affect the Probe's parachute-descent trajectory. A proper estimation of the zonal wind was of paramount importance for designing the Probe-to-Orbiter radio relay link geometry, and hence the Orbiter trajectory during the Probe descent. The wind model used was derived by Flasar et al. from the measured latitudinal thermal gradients. This

model provides the amplitude of the zonal wind versus altitude, but it cannot predict whether the wind blows west-to-east or east-to-west. Both directions have been assumed to be of equal probability for designing the radio link.

Other models

Other models were established for designing the Probe, including:

- the lightning model (Probe susceptibility to lightning)
- the surface radar reflectivity (design of the Probe radar)
- the moist convection model (Probe icing risk)
- wind gust model (parachute stability)
- gravity-wave model (noise on the entry profile)
- S-band signal attenuation in Titan's atmosphere (radio link performance).

All of the models used in designing the Probe are documented in ESA SP-1177.

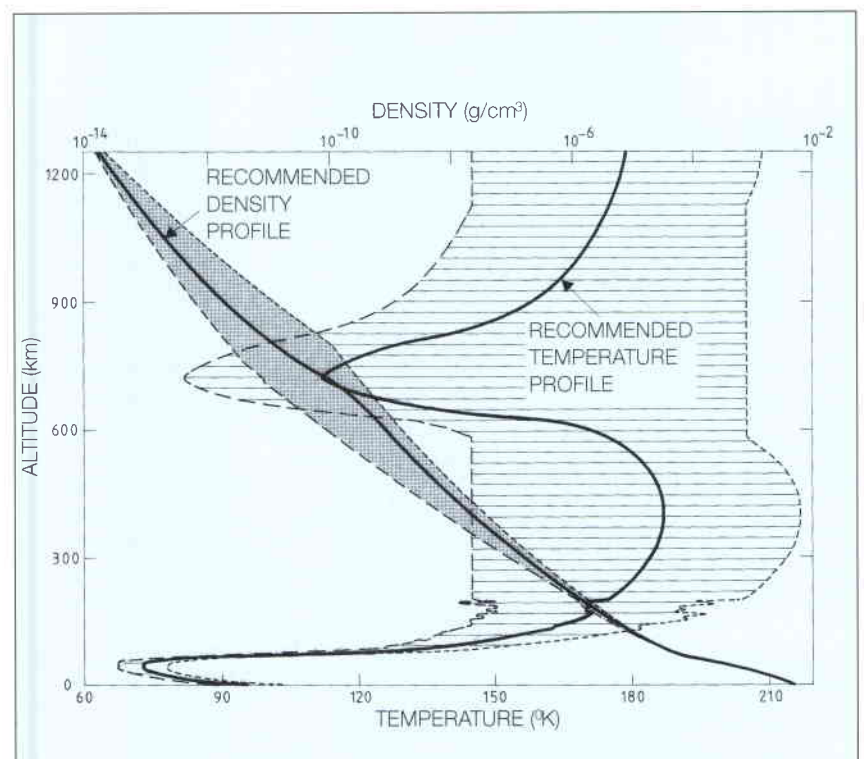
The Huygens payload consists of six instruments provided by the Principal Investigators. The principal instrument characteristics are listed in Table 2, and a brief description of each instrument is provided below. More detailed descriptions are provided in ESA SP-1177, which also includes papers on the interdisciplinary science investigations.

The Huygens payload

The Gas Chromatograph and Mass Spectrometer (GCMS)

GCMS is a highly versatile gas chemical analyser designed to identify and quantify the

Figure 4. The Lellouch-Hunten Titan atmosphere model used as the 'engineering model' for designing the Huygens heat shield and parachutes. This model comprises three profiles taking account of all thermal uncertainties



abundance of the various atmospheric constituents. It can analyse argon and other noble gases and make isotopic measurements. The GCMS inlet system is located near the apex in front of the Probe, where the dynamic

pressure drives the gas into the instrument. GCMS works either in direct mass-spectrometer mode, or in the more powerful mode in which the gas sample is passed through gas-chromatograph columns to

Table 2. The principal characteristics of the Huygens payload

<i>Instrument/PI</i>	<i>Science objectives</i>	<i>Sensors/Measurements</i>
Huygens Atmospheric Structure Instrument (HASI) M. Fulchignoni, University Paris 7/ Obs. Paris-Meudon (France)	Atmospheric temperature and pressure profile, winds and turbulence. Atmospheric conductivity. Search for lightning. Surface permittivity and radar reflectivity.	<i>T</i> : 50-300K, <i>P</i> : 0-2000 mbar, γ : 1 μ g-20 mg AC <i>E</i> -field: 0-10 kHz, 80 dB at 2 μ V/m Hz ^{1/2} DC <i>E</i> -field: 50 dB at 40 mV/m Conductivity: 10 ⁻¹⁵ Ω /m to ∞ Relative permittivity: 1 to ∞ Acoustic: 0-5 kHz, 90 dB at 5 mPa
Gas Chromatograph Mass Spectrometer (GCMS) H.B. Niemann, NASA/GSFC, Greenbelt (USA)	Atmospheric composition profile. Aerosol pyrolysis products analysis.	Mass range: 2-146 dalton Dynamic range: >10 ⁸ Sensitivity: 10 ⁻¹⁰ mixing ratio Mass resolution: 10 ⁻⁶ at 60 dalton GC: 3 parallel columns, H ₂ carrier gas Quadrupole mass filter 5 electron impact sources Enrichment cells (x100-x1000)
Aerosol Collector and Pyrolyser (ACP) G.M. Israel, SA/CNRS Verrières-le-Buisson (France)	Aerosol sampling in two layers - pyrolysis and injection to GCMS.	2 samples: 150-40 km, 23-17 km 3-step pyrolysis: 20°C, 250°C, 650°C
Descent Imager/Spectral Radiometer (DISR) M.G. Tomasko, University of Arizona, Tucson (USA)	Atmosphere composition and cloud structure. Aerosol properties. Atmosphere energy budget. Surface imaging.	Upward and downward visible (480-960 nm) and IR (0.87-1.64 μ m) spectrometers, res. 2.4/6.3 nm. Downward and side looking imagers (0.660-1 μ m), res. 0.06-0.20° Solar Aureole measurements: 550±5 nm, 939±6 nm. Surface spectral reflectance with surface lamp.
Doppler Wind Experiment (DWE) M.K. Bird, University of Bonn (Germany)	Probe Doppler tracking from the Orbiter for zonal wind profile measurement.	(Allan Variance) ^{1/2} : 10 ⁻¹¹ (1 s); 5 × 10 ⁻¹² (10 s); 10 ⁻¹² (100 s) Wind measurements 2-200 m/s Probe spin, signal attenuation
Surface Science Package (SSP) J.C. Zarnecki University of Kent, Canterbury (UK)	Titan surface state and composition at landing site. Atmospheric measurements.	γ : 0-100 g; tilt ±60°; <i>T</i> : 65-110K; <i>T</i> _{th} : 0-400 mW m ⁻¹ K ⁻¹ Speed of sound: 150-2000 ms ⁻¹ , Liquid density: 400-700 kg m ⁻³ , Ref. index: 1.25-1.45 Acoustic sounding, liquid relative permittivity

separate components of similar mass before analysis with the mass spectrometer. The instrument is also equipped with gas samplers for filling at high altitude, for analysis later in the descent when there is more time available. The

instrument is equipped with a separate ionisation chamber for analysis of the aerosol pyrolyser products fed by the ACP, the instrument described next. Thanks to its heated inlet, GCMS can also measure the

<i>Mass (kg)</i>	<i>Power (typical/ peak) (W)</i>	<i>Energy (during descent) (Wh)</i>	<i>Typical data rate (bit/s)</i>	<i>Participating Countries</i>
6.3	15/85	38	896	I, A, D, E, F, N, SF, USA, UK, ESA/SSD, IS, PL
17.3	28/79	115	960	USA, A, F
6.3	3/85	78	128	F, A, USA
8.1	13/70	42	4800	USA, D, F
1.9	10/18	28	10	D, I, USA
3.9	10/11	30	704	UK, F, USA, ESA/SSD

composition of a vaporised surface sample in the event that a safe landing allows the collection and transmission of data for several minutes.

The Aerosol Collector and Pyrolyser (ACP)

ACP is designed to collect aerosols for GCMS to analyse their chemical compositions. It is equipped with a deployable sampling device that will be operated twice in order to collect the aerosols from two atmospheric layers: the first from the top of the atmosphere down to about 40 km, and the second in the cloud layer from about 23 km down to 17 km. After extension of the sampling device, a pump draws the atmosphere and its aerosols through filters in order to capture the aerosols. At the end of each sampling, the filter is retracted into an oven where the aerosols are heated to three, increasing, temperatures in order to conduct a step pyrolysis. The volatiles are vaporised first at the lowest temperature, then the more complex less volatile organic material, and finally the core of the particles. The products are flushed to GCMS for analysis, thereby providing spectra for each analysis step.

Descent Imager/Spectral Radiometer (DISR)

DISR is a multi-sensor optical instrument capable of imaging and making spectral measurements over a wide range of the optical spectrum (ultraviolet-infrared, 0.3-1.64 μm).

An important feature of Titan is its aerosols and thick atmosphere, where the temperature structure is determined by the radiative and convective heat-transport processes. DISR measures the upward and downward heat fluxes. An aureole sensor measures the intensity of the Sun's halo, yielding the degree of sunlight scattering caused primarily by the column density of aerosols along the line of sight. This in turn allows deduction of the aerosols' physical properties. DISR is also equipped with a side-looking horizon instrument to image the clouds.

DISR also has the ability to address one of Huygens' prime objectives: investigating the nature and composition of the surface. Two cameras (one visible, one infrared) looking downwards and sideways image the surface and, as Huygens spins slowly, build up mosaic panoramas. By recording several panoramas during the last part of the descent, it may be possible to infer the Probe's drift (if the surface is not featureless) and contribute to the wind measurements.

Titan's daytime surface brightness is about 350 times that of nighttime on Earth with a full Moon. While the surface illumination is

adequate for imaging, a surface lamp will be activated a few hundred metres up to provide enough light in the methane absorption bands for spectral-reflectance measurements. These will provide unique information on the composition of the surface material.

Evaluation of the gas flow around the Descent Module during the 1 min phase of back-cover separation and heat-shield release showed there was a small risk of contaminating DISR's optical windows. A cover was later added for safety and it will be ejected shortly after the heat shield is released. Should its release mechanism fail, the cover is provided with optical windows that would still allow measurements to be made with it still in place.

Huygens Atmosphere Structure Instrument (HASI)

HASI is also a multi-sensor instrument, intended to measure the atmosphere's physical properties, including its electrical properties. Its set of sensors comprises a three-axis accelerometer, a redundant set of a coarse and a fine temperature sensor, a multi-range pressure sensor and an electric-field sensor array.

The set of accelerometers is specifically optimised to measure entry deceleration for inferring the atmosphere thermal profile during entry.

The electric-field sensor comprises a relaxation probe to measure the atmosphere's ion conductivity and a quadrupolar array of electrodes for measuring, by using the mutual impedance probe technique, atmosphere permittivity and surface-material permittivity after and possibly just before impact, when the Probe is still a few metres above the surface. Two electrodes of the quadrupolar array are also used as an electric antenna to detect atmospheric electromagnetic waves, such as those produced by lightning.

Several of HASI's sensors require accommodation on booms. The temperature and pressure sensors are mounted on a fixed stub, which is long enough to protrude into the free flow. The electrical sensors are mounted on a pair of deployable booms in order to minimise the shielding effects of the Probe body.

The capability for processing the surface-reflected signal of the radar altimeter (the altitude sensor is provided as part of the Probe system, as described later) was added to HASI late in the programme. This additional function allows it to return important information about the surface topography and radar properties below the Probe along its descent track.

Doppler Wind Experiment (DWE)

DWE uses one of the two redundant chains of the Probe-Orbiter radio link. It required the addition of two ultra-stable oscillators (USOs) to one chain of the Probe data-relay subsystem. The Probe Transmitter USO (TUSO) provides a very stable carrier frequency to the Probe-to-Orbiter radio link; the Receiver USO (RUSO) aboard the Orbiter provides an accurate reference signal for Doppler processing of the received carrier signal. The Probe wind drift will induce a measurable Doppler shift in the carrier signal, and that signature will be extracted aboard the Orbiter and merged into the Probe data stream recorded on the Orbiter solid-state recorders. It is expected that the Doppler measurements will be so sensitive that, by having the Probe transmit antennas offset from the spin axis by a few centimetres, the Probe spin rate and spin phase will also be determined. The Probe's swinging motion under the parachute and other radio-signal perturbing effects, such as atmospheric attenuation, may also be detectable from the signal.

The chain provided with the TUSO and RUSO is also equipped with the same standard oscillators that equip the other radio relay link chain. Selecting between the DWE USOs (the default configuration) and the standard oscillators will be done during the Probe configuration activity before its release from the Orbiter.

Surface Science Package (SSP)

SSP comprises a suite of rather simple sensors for determining the surface physical properties at the impact site and for providing unique information on the composition of the surface material. The SSP package includes a force transducer for measuring the impact deceleration, and other sensors to measure the refractive index, temperature, thermal conductivity, heat capacity, speed of sound and dielectric constant of the (liquid) material at the impact site. The SSP also includes an acoustic sounder to be activated a few hundred metres up for sounding the atmosphere's bottom layer and the surface's physical characteristics before impact. If Huygens lands in a liquid, the acoustic sounder will be used in a sonar mode to probe the liquid's depth. A tilt sensor is included to indicate the Probe's attitude after impact. Although SSP's objectives are mainly to investigate the surface, several sensors will contribute significantly to the studies of atmospheric properties during the whole descent phase.

The Huygens mission

The Huygens Probe is carried to Titan attached

to the Saturn Orbiter. It is released after Saturn Orbit Insertion (SOI) during the initial orbit around Saturn, nominally 22 days before Titan encounter, as shown in Figure 3. Shortly after release, the Orbiter executes a deflection manoeuvre to establish the proper radio communication geometry with Huygens during the Probe's descent phase, and also to set the initial conditions for the satellite tour after completion of the Probe mission.

Huygens separates from the Orbiter at 30 cm/s and a spin rate of 7 rpm for stability during the coast and entry phases. The entry subsystem consists of the 2.75 m-diameter front heat shield and the aft cover, both protected against the radiative and convective heat fluxes generated during the entry phase at 350-220 km altitude, where Huygens decelerates from about 6 km/s to 400 m/s (Mach 1.5) in less than 2 min.

At Mach 1.5, the parachute deployment sequence initiates, starting with a mortar pulling out a pilot chute, which in turn pulls away the aft cover. After inflation of the 8.3 m-diameter main parachute, the front heat shield is released to fall from the Descent Module (DM). Then, after a 30 s delay built into the sequence 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 protracted descent, and a smaller 2.5 m diameter parachute is deployed.

The major events of the entry and descent sequence are illustrated in Figure 5. The altitude profile is shown in Figure 6, where the middle curve indicates the nominal profiles and the two other curves define its envelope, taking into account the Lellouch-Hunten atmospheric model uncertainties and all other descent calculation uncertainties.

After separation from the Orbiter, the only energy source is from primary batteries with a total capacity of 1800 Wh. The batteries and all other resources are sized, with a comfortable margin, for a maximum mission duration of 153 min, corresponding to a maximum descent time of 2.5 h and at least 3 min on the surface. Instrument operations are based either on time in the top part of the descent or on measured altitude (from the system-provided radar altimeter) in the bottom part.

Huygens transmits its data at a constant 8 kbit/s to the overflying Orbiter, which points its HGA to a pre-defined location on Titan for a

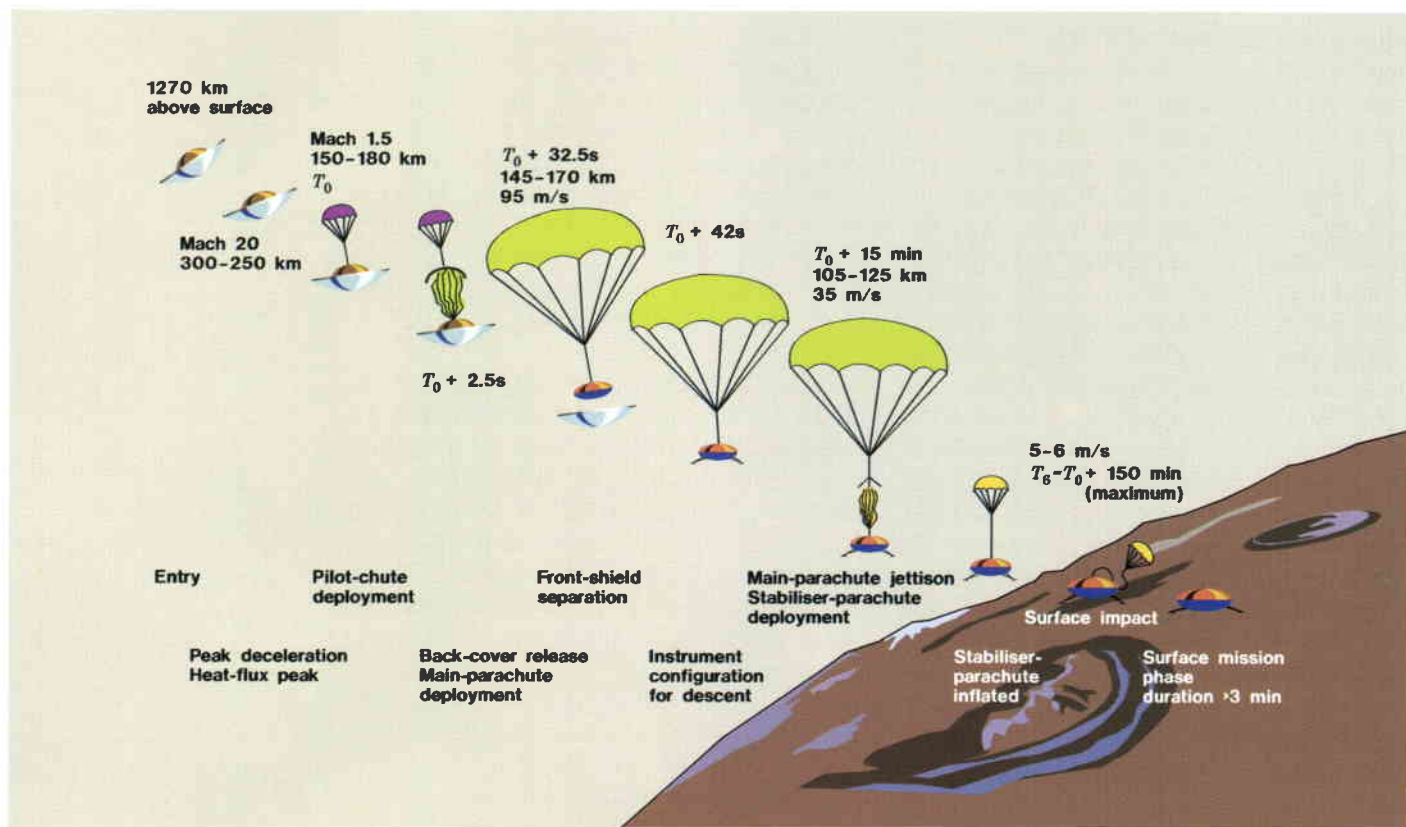


Figure 5. The Huygens Probe entry and descent sequence

full 3 h to allow for data reception after landing for 43 min for a nominal descent time of 137 min. The Probe data are stored onboard the Orbiter in the two solid-state recorders for later transmission to Earth as soon as the HGA can be redirected after Huygens has completed its mission.

transfer ACP's pyrolyser products to GCMS for analysis. A serial link between the two instruments synchronises their operations.

DISR consists of two boxes: the Sensor Head (DISR-S) and the Electronics box (DISR-E). DISR-S is mounted on the platform's periphery to accommodate the field-of-view and scanning requirements. DISR-E is mounted on the platform's inner area and connected to the DISR-S via a short harness.

HASI's sensors, with the exception of the accelerometers, are mounted either on a fixed stub (HASI STUB) or on deployable booms (HASI boom 1 and boom 2). This satisfies post-deployment requirements for access to the gas flow for pressure and temperature measurements, while minimising Probe-induced perturbations to the electric-charge distribution at the electric-field sensors. The accelerometers are located near the Probe's centre of gravity in its entry configuration. All HASI sensors are connected to the central electronics box (HASI-DPU), which contains the conditioning pre-amplifiers and the central processing functions. The electric antenna pre-amplifiers are housed in two small boxes located as close as possible to the sensors, but still inside the Descent Module, in order to minimise the cable length.

SSP consists of two boxes: the 'Top Hat' structure (SSP-TH) that accommodates all but two of the sensors, and an electronics box

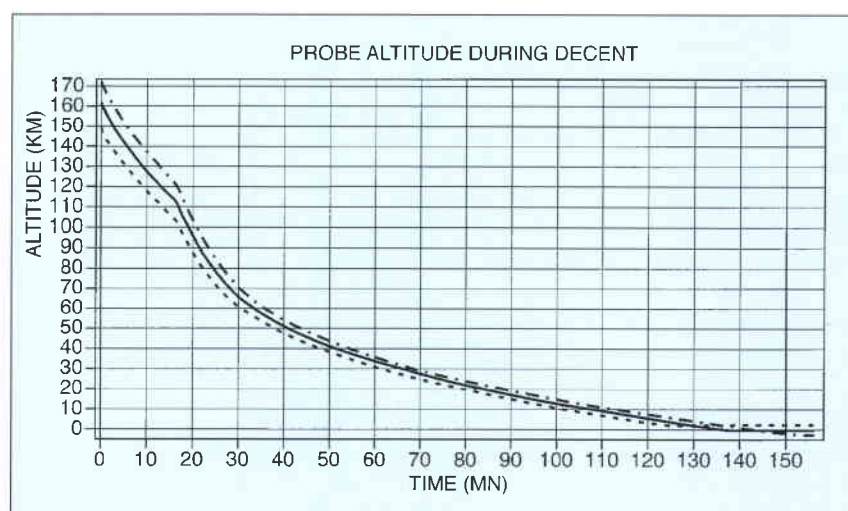


Figure 6. The altitude descent profile for the three atmospheric profiles of the Lellouch-Hunten model

Payload accommodation

Mechanical accommodation

All the payload elements described above are accommodated on the payload platform, as shown in Figure 7. ACP and GCMS are both single-box instruments with their inlets below Huygens for direct access to the gas flow. Each also has an exhaust tube projecting through the top platform. ACP and GCMS are linked by a temperature-controlled pneumatic line to

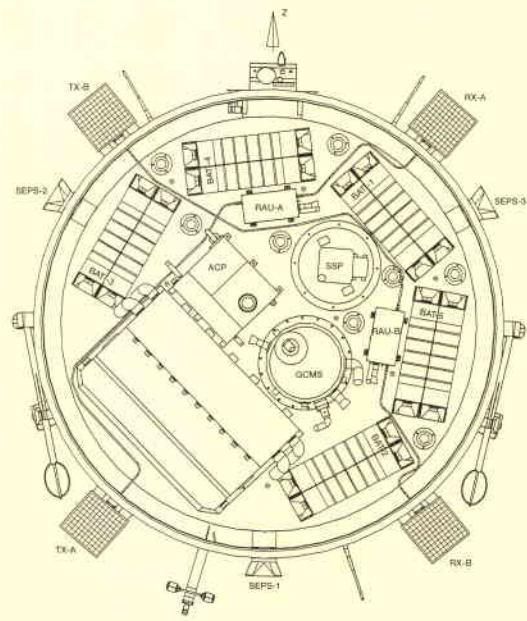
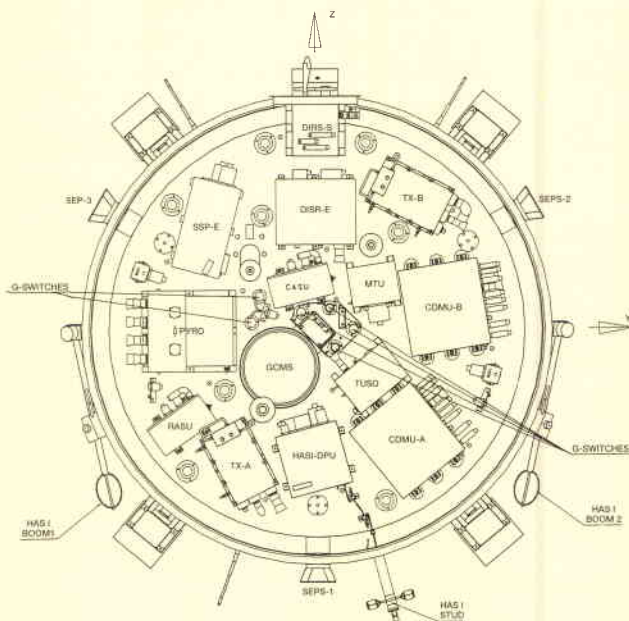
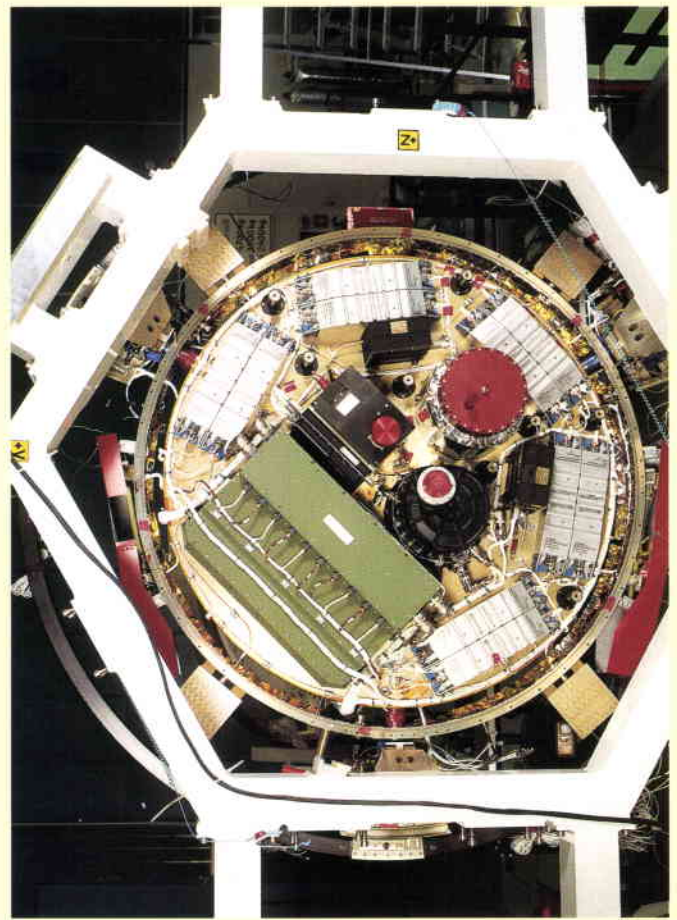
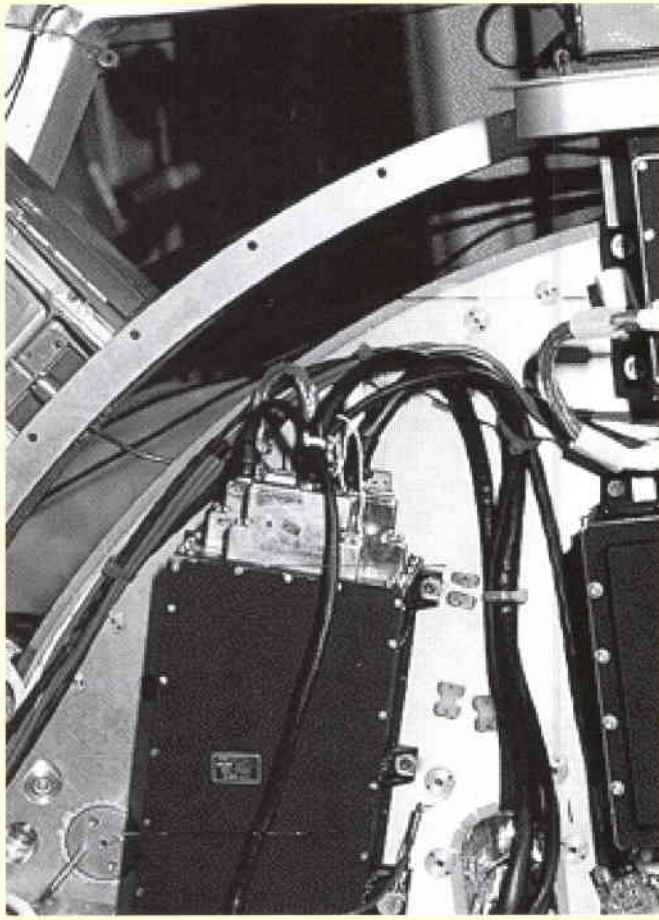


Figure 7. Accommodation of the payload and the major subsystems on the top/bottom of the experiment platform

ACP: Aerosol Collector Pyrolyser; BAT-1/5: Batteries; CASU: Central Acceleration Sensor Unit; CDMU-A/B: Command and Data Management Unit; DISR: Descent Imager/Spectral Radiometer; DISR-E: DISR Electronics Box; DISR-S: DISR Sensor Head; GCMS: Gas Chromatograph Mass Spectrometer; HASI: Huygens Atmospheric Structure Instrument; MTU: Mission Timer Unit; PCDU: Power Conditioning and Distribution Unit; PYRO: Pyro Unit; RASU: Radial Acceleration Sensor Unit; RUSO: Receiver Ultra Stable Oscillator; RX-A/B: Receiver Antennas for Radar Altimeter A/B; SEPS: Separation Subsystem; SSP: Surface Science Package; SSP-E: SSP Electronics Box; TUSO: Transmitter Ultra Stable Oscillator; TX-A/B: Transmit Antennas for Radar Altimeter A/B.

(SSP-E). SSP-TH is below the platform, allowing for sensor wetting in case of landing in a liquid. It is connected to SSP-E (on the top of the platform) via a harness through the platform. SSP-TH is also instrumented with a pylon designed for effective transmission of the impact deceleration to the force transducer on the platform. Two sensors are directly mounted on the electronics box: the tilt meter and one of the two accelerometers.

DWE's TUSO is also accommodated on the experiment platform, while RUSO is accommodated in the part of Huygens that remains attached to the Orbiter (Probe Support Equipment, PSE).

The overall accommodation of the payload sensors that require direct access to Titan's atmosphere is illustrated in Figure 8.

Probe spin requirements

Huygens is required to spin throughout the descent to provide the azimuth coverage needed by several sensors. The real-time spin information requirements are imposed by DISR and are very stringent for the final part of the descent for imaging the surface, in order to adapt the time delay between consecutive frames during the mosaic image-taking cycle. The spin is induced by a set of 36 vanes mounted on the bottom part of the fore dome. The spin rate is measured by a set of system-provided accelerometers covering the 0-15 rpm range with an accuracy of 0.1 rpm.

Probe altitude measurements

During the early descent, instrument operations are time-based. However, for maximising the science return, the measurement cycle during the last part of the descent is based on the true altitude. Furthermore, as impact survival is not guaranteed by the Probe's design, maximum science return can be achieved from the last few hundred metres and possibly for the crucial first few seconds after impact if the altitude is reliably known. To meet these requirements, altitude is measured by a set of two radio altimeters working in the Ku-band (15.3 and 15.7 GHz). The measurements are processed by a sophisticated algorithm in the Probe's central computer that will fall back on the default time-based altitude table in case of a temporary loss of radar lock, e.g. caused by a higher than nominal pendulum motion.

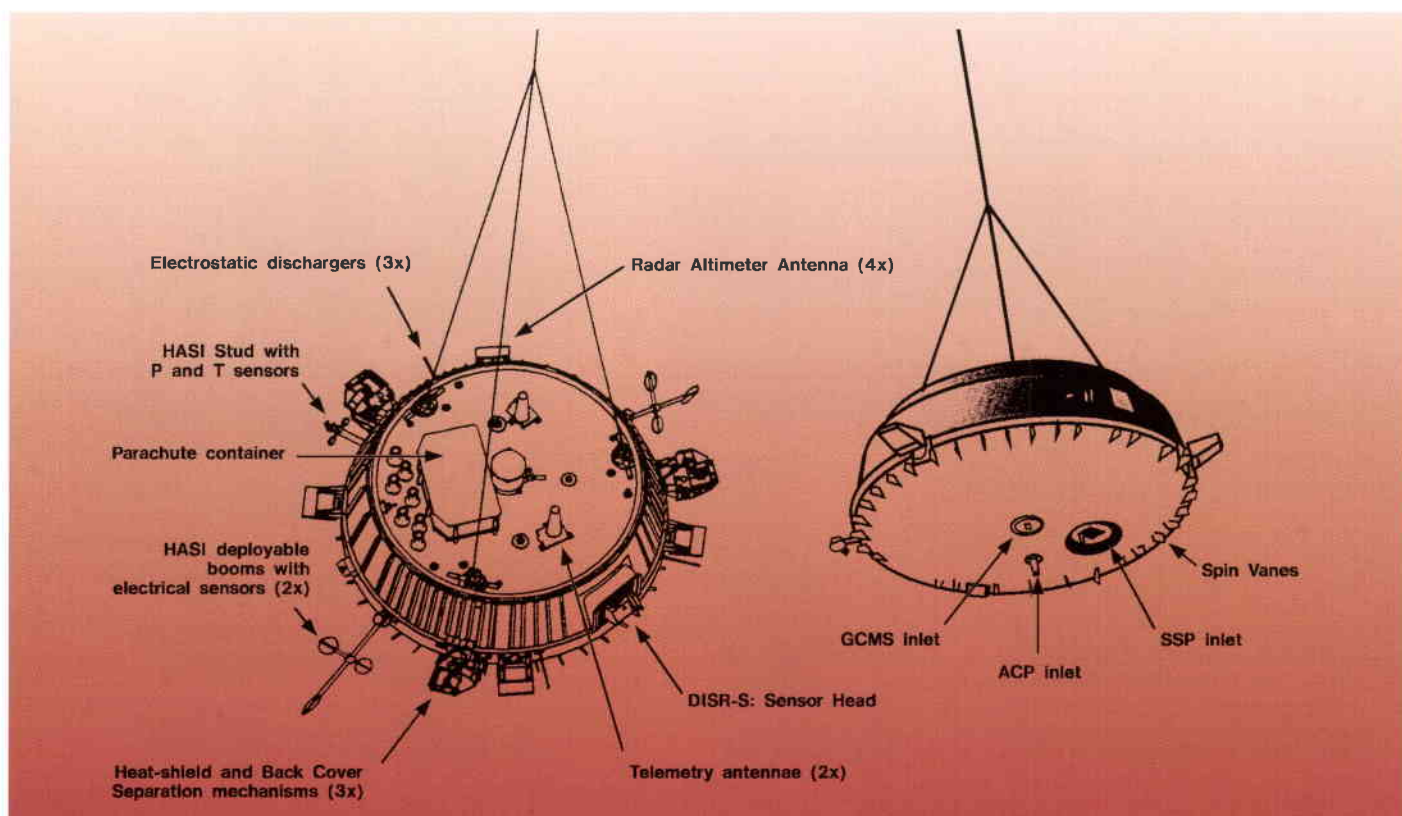
The Descent Data Broadcast (DDB) pulse

The Probe time, measured spin and processed altitude are broadcast every 2 seconds to all experiments for their real-time use during descent. The DDB altitude information is used by DISR, HASI and SSP to optimise their measurement cycle.

Probe targeting requirements

Targeting requirements are imposed by the payload and certain system design aspects, such as the telecommunications geometry and the design of the heat-shield ablative material, which are affected by the choice of entry point. DISR and DWE impose demanding require-

Figure 8. The Huygens Probe under its parachute. The HASI booms are deployed and the DISR sensor head can be seen. At right, the accommodation of the GCMS, ACP and SSP inlets is shown



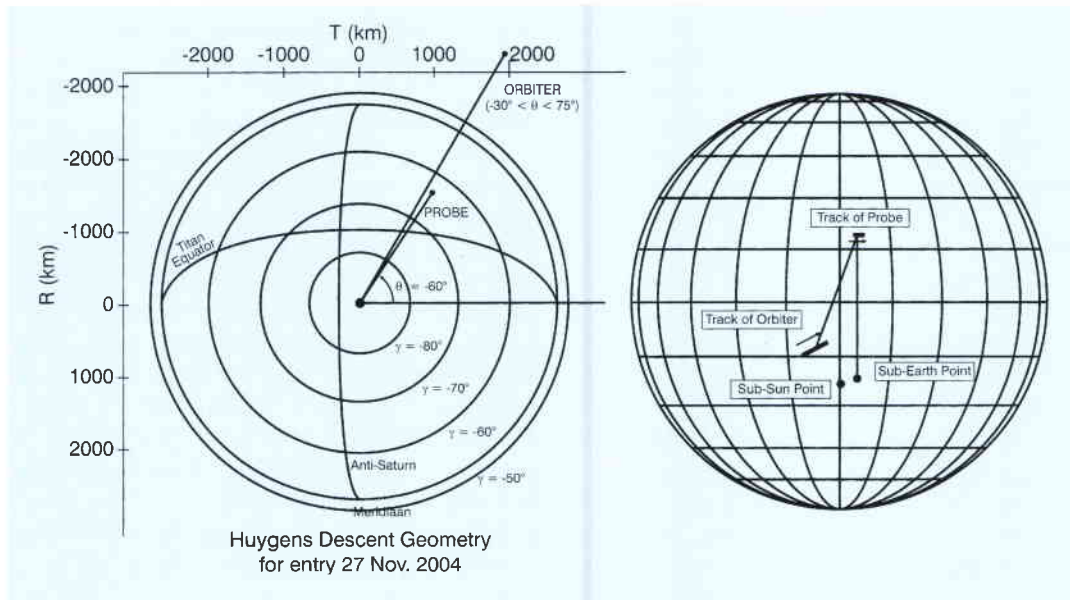


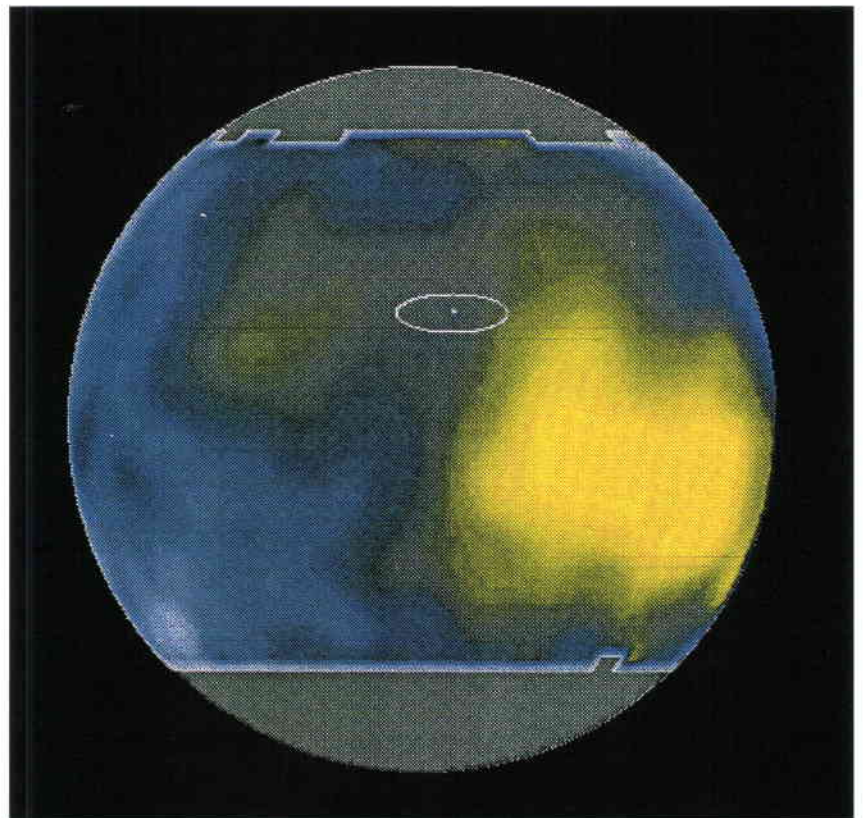
Figure 9. Probe targeting (B-plane) and entry geometry

ments on the Sun Zenith Angle (SZA), which should lie within 35-65°, and the maximisation of the zonal wind component along the Probe-Orbiter line of sight. As a result of all the targeting trade-offs, made early during Phase-B, an entry angle of -64° was selected. Entry and descent occur over Titan's sunlit hemisphere (Fig. 9). Figure 10 shows the landing ellipse on images obtained by the Hubble Space Telescope. It so happens that the landing site is ideally located – Huygens will fly over the region of highest contrast on Titan.

Entry measurements

Only HASI will perform measurements during the entry phase. These and all data acquired by the other instruments before the Orbiter radio link is established will be buffered within each instrument and interleaved with the real-time data packets that are transmitted by each instrument when the link is made.

Huygens operates autonomously after separation from the Orbiter, the radio link to the Orbiter being one-way for telemetry only. Until separation, telecommands can be sent via an umbilical from the Orbiter (which also provides electrical power to the Probe), but this facility will be used only during the cruise and Saturn-orbit phases for monitoring the health of subsystems, maintaining mechanical devices and routinely calibrating the instruments for the biannual checkouts. There will be no scientific measurements before Titan arrival, and Huygens will be switched off throughout most of the cruise phase. During the 22-day coast phase, after separation from the Orbiter, only a triply-redundant timer will operate to wake up Huygens shortly before the predicted entry into Titan's atmosphere. Loading the value of this timer's duration and depassivation of the batteries that power the Probe after separation



will be the last activities initiated by ground command.

Flight operations

Probe operation and the collection of telemetered data are controlled from a dedicated control room, the Huygens Probe Operations Centre (HPOC), at ESOC in Darmstadt (D). Here, command sequences are generated and transferred by dedicated communication lines to the Cassini Mission Support Area (MSA) at the Jet Propulsion Laboratory (JPL), Pasadena, California. There, the Probe sequences are merged with commands to be sent to other subsystems and

Figure 10. Hubble Space Telescope image of Titan with the Huygens 200 km × 1200 km landing ellipse. The entry location was selected before such HST images became available, but it turns out that Huygens will descend over the region of greatest surface contrast

instruments of the Orbiter for uplinking via NASA's Deep Space Network (DSN). Probe telecommands are stored by the Orbiter and forwarded to the Probe Support Equipment (PSE) at specified times (time tags) for immediate execution. Due to the great distance between Earth and Saturn (requiring up to 160 min for round-trip radio communications), real-time operation of Huygens is not possible.

Data collected by the Probe and passed to the PSE via the umbilical (during the attached phase) or the relay link (during the descent phase) are formatted by the PSE and forwarded to the Orbiter's Command and Data Subsystem (CDS). The Orbiter stores the Huygens data in its two solid-state recorders for transmission to Earth when the Orbiter is visible from one of the DSN ground stations. From the ground station, the data are forwarded to the MSA where Probe data are separated from other Orbiter data before being stored in the Cassini Project Database (PDB). Operators in the HPOC access the PDB to retrieve Probe data via a Science Operations and Planning Computer, supplied to ESOC by JPL under the terms of the inter-agency agreement.

Subsystem housekeeping data are used by ESOC to monitor Probe performance, while data from the science instruments are extracted for forwarding to the Investigators. During the cruise phase, these data are shipped to the scientists' home institutes by CD-ROM (the prime medium) and possibly by public data line. After analysing these data, the Investigators meet the Operations Team to assess the health of the payload and to define the activities for the following checkout period.

During the Saturn-orbit and Probe-mission phases, the investigators are located in HPOC to expedite their access to the data and facilitate interaction with their colleagues and the Probe flight-operations team. Accommodation will be provided for the ground-

support equipment needed to reduce and interpret their data.

Data analysis and archiving

The raw Huygens data will be provided to the Huygens Principal Investigator (PI) teams on CD-ROM after each checkout and for the descent phase. It is the responsibility of each PI team to process the data and to provide a reduced data set to allow a coordinated analysis of the Huygens data set. The Huygens Science Working Team (HSWT) intends to produce a commonly agreed descent profile within weeks of the event to allow all experimenters to analyse their data and interpret their measurements in the most efficient way. A subgroup of the HSWT, the Descent Trajectory Working Group (DTWG), has been set up to optimise the data analysis that should lead to establishing the Probe's descent profile in Titan's atmosphere, providing the optimum means for coordinating analysis of the data from the six instruments.

The initial uncertainty ellipse of the Probe's landing site may be as large as 200 × 1200 km. The HSWT will work in coordination with the Orbiter teams to reduce the uncertainty in the Probe descent trajectory to allow a proper coordinated analysis of the Probe and Orbiter data set and to help plan the observations of the Probe landing site by the Orbiter's radar and remote-sensing instruments after the Probe mission.

The Huygens data set will be archived as an integral part of the Cassini data archive that is being defined by the Cassini Project Office at JPL. This will provide the optimum approach for synergistic studies using both Probe and Orbiter data.

The Huygens Science Working Team (HSWT)

The HSWT (Table 3) manages the overall Huygens science activities. It advised the Huygens Project on all science-related matters during the Probe's development, and it will meet periodically during the cruise phase to assess the payload's performance and to prepare itself for the Huygens mission and data-analysis phase. Activities will peak during the Huygens mission phase as it coordinates the analysis and interpretation of Probe data. It will also play an important role in planning the post-Huygens observations of Titan by the Orbiter, and it will participate in joint Probe/Orbiter investigations, data analysis and interpretation studies.



Table 3. The Huygens Science Working Team (HSWT)

Chairman: Jean-Pierre Lebreton, ESA/ESTEC, Huygens Project Scientist
Vice-Chairman: Dennis Matson, NASA/JPL, Cassini Project Scientist

PI/DWE: Michael Bird, University of Bonn, Germany

PI/HAS: Marcello Fulchignoni, Université Paris 7/Observatoire Paris-Meudon, France

IDS/Aeronomy of Titan: Daniel Gautier, Observatoire Paris-Meudon, France

PI/ACP: Guy Israel, CNRS/SA Verrieres-le-Buisson, France

IDS/Titan Atmosphere-Surface Interaction: Jonathan Lunine, University of Arizona, USA

PI/GCMS: Hasso Niemann, NASA Goddard Space Flight Center, USA

IDS/Titan Organic Chemistry & Exobiology: Francois Raulin; LISA, Université Paris 12, Creteil, France

PI/DISR: Martin Tomasko, University of Arizona, USA

PI/SSP: John Zarnecki, University of Kent at Canterbury, UK

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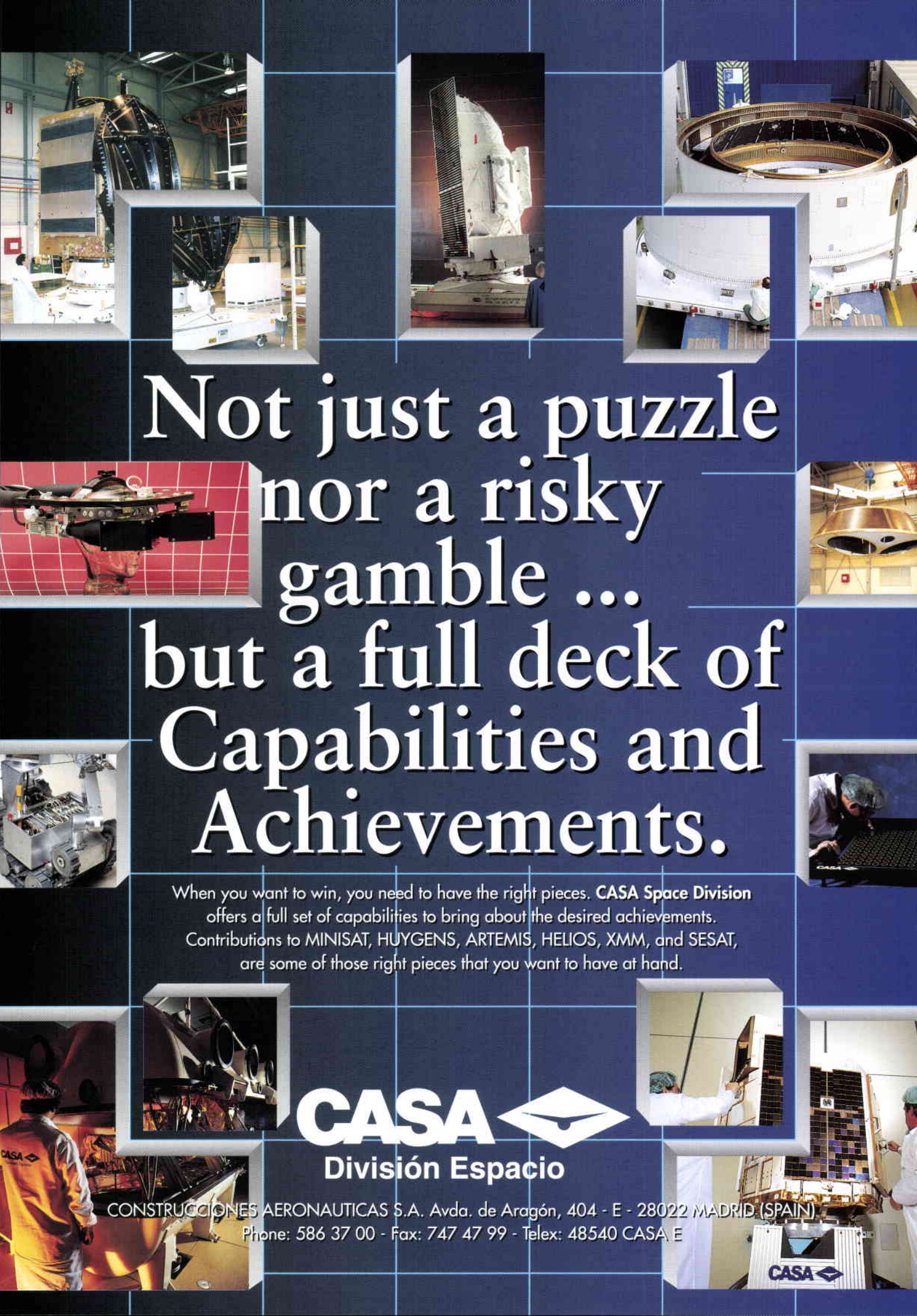
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The Huygens Probe*

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Introduction

The industrial Phase-B activities for the Huygens Probe began in January 1991 under the leadership of Aerospatiale, the prime contractor. The geographical distribution of the work on Huygens is shown in Figure 3, and the organisation of the industrial consortium that undertook that work in Figure 4. Figure 5 summarises the overall development schedule, indicating the main milestones and the major Reviews carried out at agency level.

Many engineering challenges had to be overcome in designing the first probe planned to study a moon beyond the Earth's system. An extensive development programme was undertaken (Fig. 1), involving several unusual tests, driven by the mission's unique aspects. ESA's Huygens Probe will be delivered to Titan, Saturn's largest satellite, by the Cassini Orbiter in 2004. After a dormant interplanetary journey of 6.7 years – although Huygens will be activated every 6 months for health checks – its aeroshell will decelerate it in less than 3 min from the entry speed of 6 km/s to 400 m/s (Mach 1.5) by about 160 km altitude. From that point, a pre-programmed sequence will trigger parachute deployment and heat-shield ejection (Fig. 2). The main scientific mission can then begin, lasting for the whole of the Probe's 2-2.5 h descent.

The Huygens Probe System consists of two principal elements:

- the 318 kg Huygens Probe, which enters Titan's atmosphere after separating from the Saturn Orbiter
- the 30 kg Probe Support Equipment (PSE), which remains attached to the Orbiter after Probe separation.

Table 1 provides the mass breakdown.

The Probe (Fig. 6) consists of the Entry Assembly (ENA) cocooning the Descent Module (DM). The ENA provides Orbiter attachment, umbilical separation and ejection, cruise and entry thermal protection, and entry deceleration control. It is jettisoned after entry, releasing the Descent Module. The latter comprises an aluminium shell and inner

structure containing all of the experiments and Probe support subsystems, including the parachute descent and spin control devices.

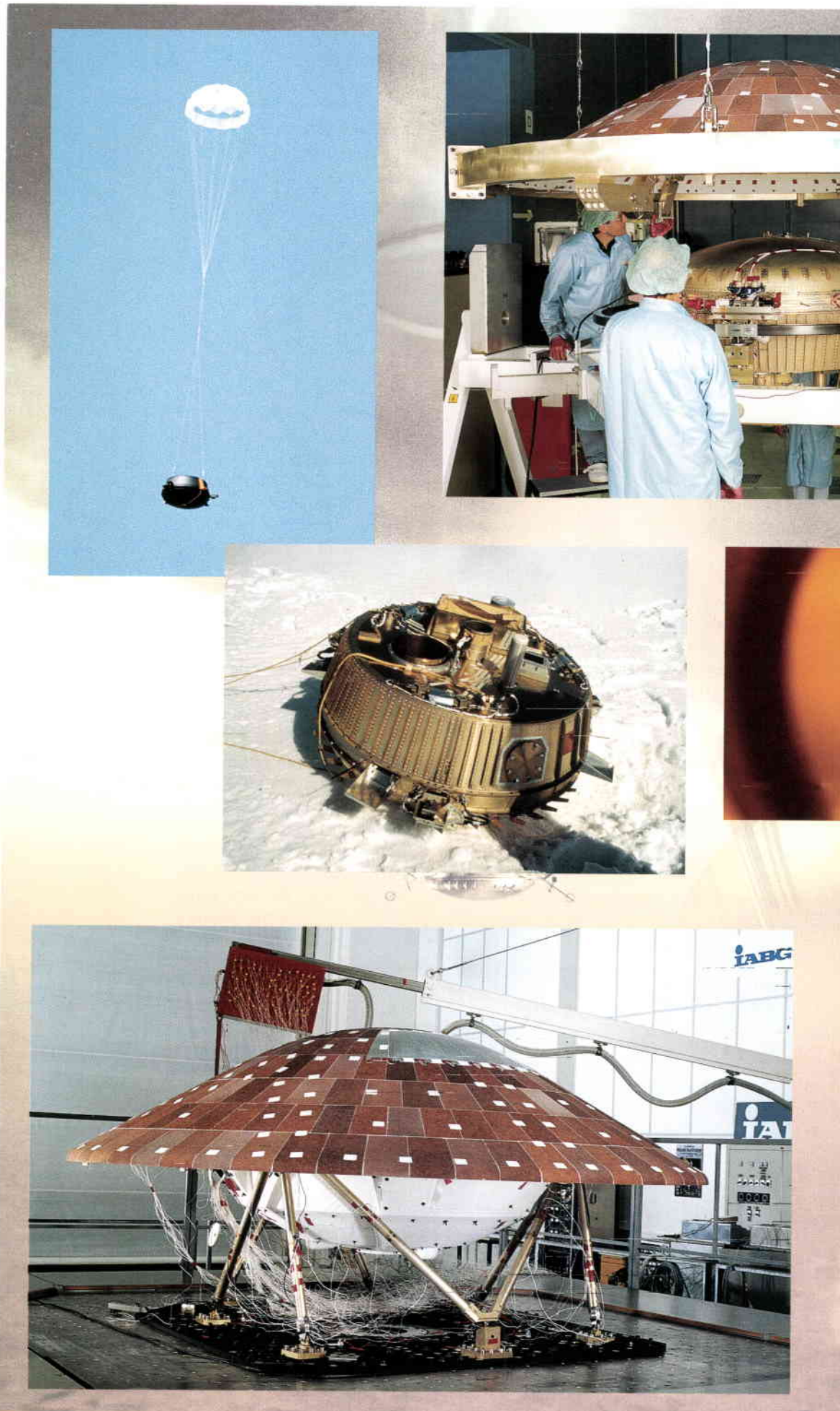
Table 1. Huygens mass budget

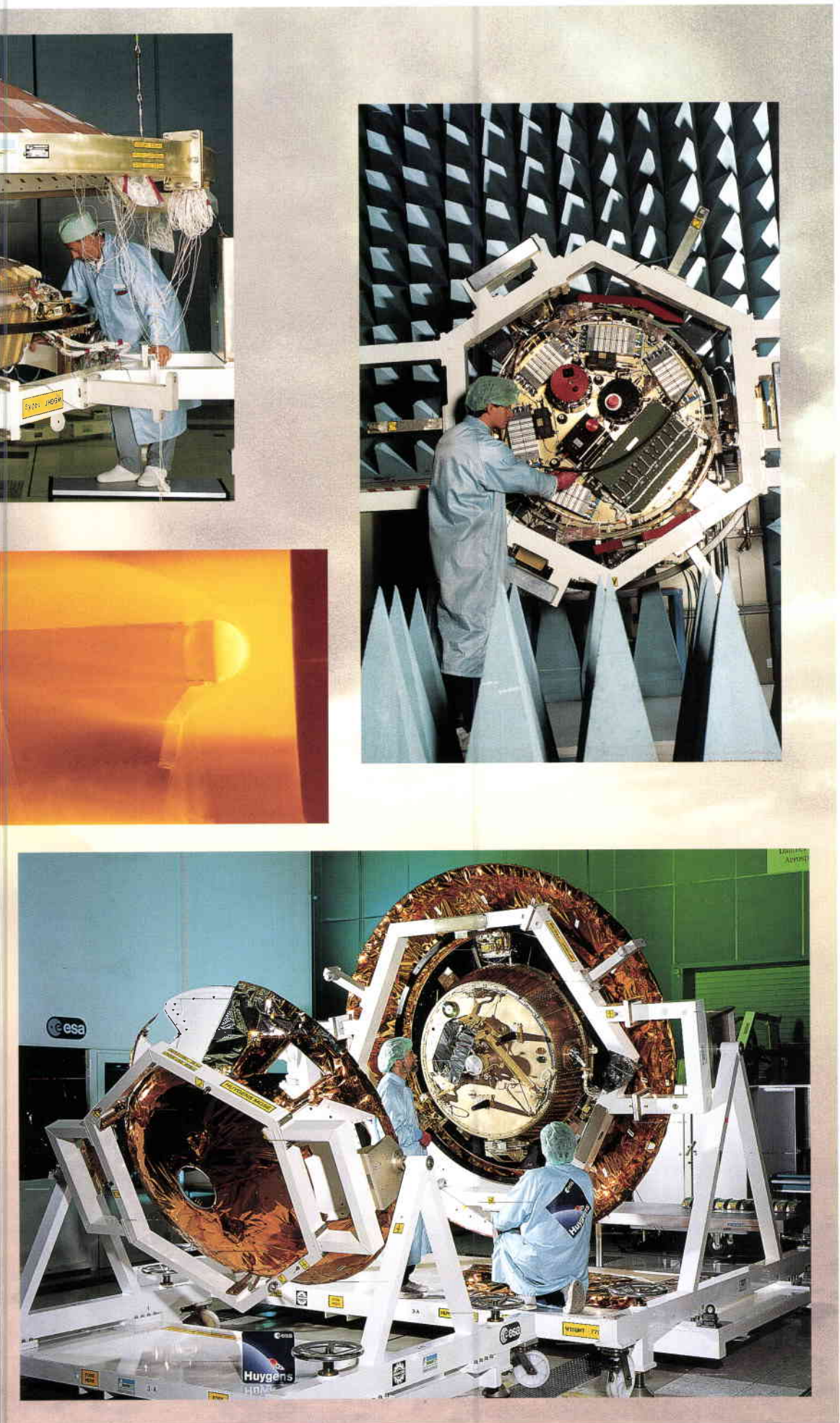
	Probe	PSE
<i>Subsystems</i>		
FRSS	78.75	
BCSS	16.13	
SEPS	11.40	10.29
DCSS	12.13	
ISTS	41.41	
THSS	20.60	1.50
EPSS	44.73	
PHSS	12.61	
CDMS	23.10	
PDRS	6.04	16.30
<i>Experiments</i>		
TUSO/RUSO	1.90	1.90
SSP	4.87	
GCMS	17.20	
HASI	5.77	
DISR	8.07	
DISR Cover	3.63	
ACP	6.18	
Fasteners, etc.	0.95	
Balance mass	2.85	
Total	318.32	29.99

PSE: Probe Support Equipment (on Orbiter); FRSS: Front Shield Subsystem. BCSS: Back Cover Subsystem. SEPS: Separation Subsystem. DCSS: Descent Control Subsystem. ISTS: Inner Structure Subsystem. THSS: Thermal Subsystem. EPSS: Electrical Power Subsystem. PHSS: Probe Harness Subsystem. CDMS: Command and Data Management Subsystem. PDRS: Probe Data Relay Subsystem. TUSO/RUSO: Transmitter/Receiver Ultra Stable Oscillator; SSP: Surface Science Package; GCMS: Gas Chromatograph Mass Spectrometer. HASI: Huygens Atmospheric Structure Instrument. DISR: Descent Imager/Spectral Radiometer. ACP: Aerosol Collector and Pyrolyser.

* Adapted from the article 'The Huygens Probe System Design' by Jones & Giovagnoli, in *Huygens: Science, Payload and Mission*, ESA SP-1177.

Figure 1. Scenes from the Huygens development programme





The PSE consists of:

- four electronic boxes aboard the Orbiter: two Probe Support Avionics (PSA), a Receiver Front End (RFE) and a Receiver Ultra Stable Oscillator (RUSO)
- the Spin Eject Device (SED)
- the harness (including the umbilical connector) providing power and RF and data links between the PSA, Probe and Orbiter.

The overall Probe System configuration and its relation to the Orbiter is shown functionally in Figure 7 and pictorially in Figure 8. Figure 9 illustrates the breakdown into the various subsystems, each of which is described below.

Mechanical/thermal subsystems

Front Shield Subsystem (FRSS)

The 79 kg, 2.7 m diameter, 60° half-angle conical spherical Front Shield will decelerate the Probe in Titan's upper atmosphere from about 6 km/s at entry, to a velocity equivalent to about Mach 1.5 by around 160 km altitude. Tiles of AQ60 ablative material, a felt of silica fibres reinforced by phenolic resin, provide protection against

the entry's 1 MW/m² thermal flux. The shield is then jettisoned and the Descent Control Subsystem (DCSS) is deployed to control the DM's descent to the surface.

The FRSS supporting structure is a CFRP honeycomb shell, to which the AQ60 tiles are attached with CAF/730 adhesive. Prosial, a suspension of hollow silica spheres in silicon elastomer, is sprayed directly on to the aluminium structure of the FRSS rear surfaces, where fluxes are ten times lower.

Back Cover Subsystem (BCSS)

The Back Cover protects the DM during entry, ensures depressurisation during launch and carries multi-layer insulation (MLI) for the cruise and coast phases. Since it does not have to meet stringent aerothermodynamic requirements, it is a stiffened aluminium shell of minimal mass (11.4 kg) protected by Prosial (5 kg). It includes: an access door for late access during integration and for forced-air ground cooling of the Probe; a break-out patch through which the first (drogue) parachute is fired; a labyrinth sealing joint with the Front Shield, providing a non-structural thermal and particulate barrier.

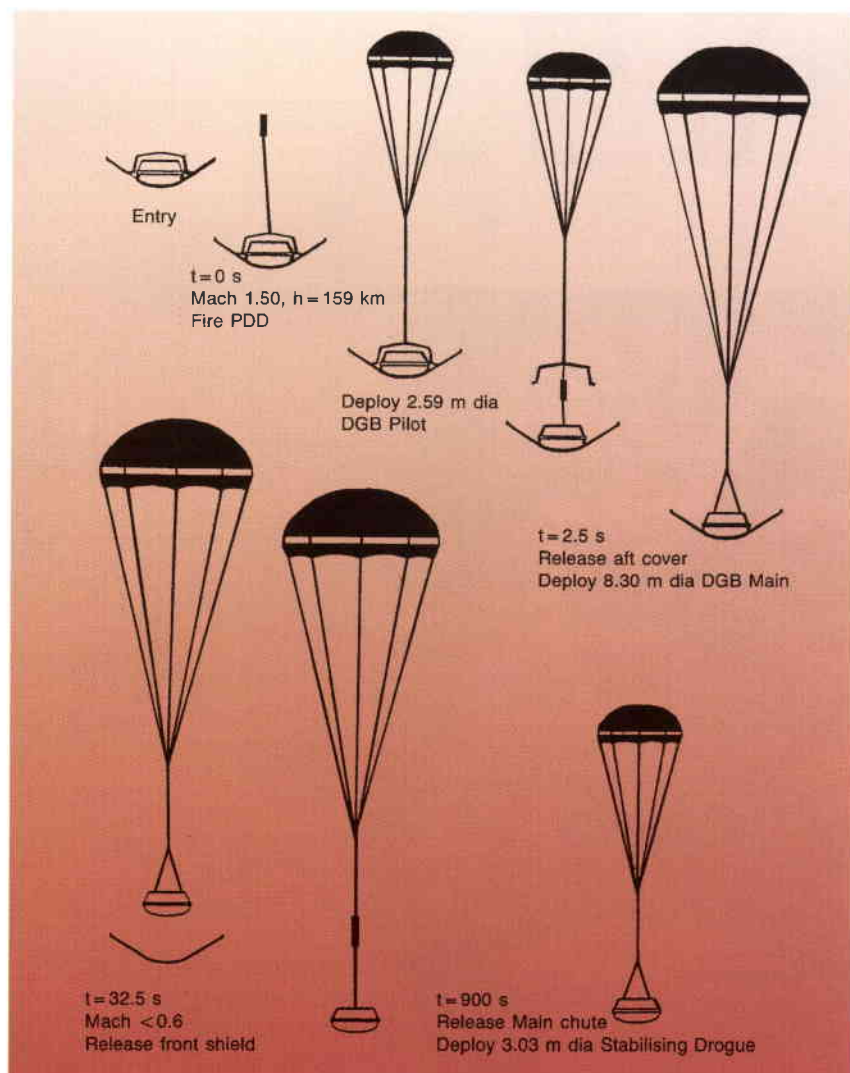
Descent Control Subsystem (DCSS)

The DCSS controls the descent rate to satisfy the scientific payload's requirements, and the attitude to meet the requirements of the Probe-Orbiter radio-frequency (RF) data link and of the descent camera's image-taking.

The DCSS is activated nominally at Mach 1.5 and about 160 km altitude. The sequence (Fig. 2) begins by firing the Parachute Deployment Device (PDD) to eject the pilot chute pack through the Back Cover's break-out patch, the attachment pins of which shear under the impact. The 2.59 m-diameter Disk Gap Band (DGB) pilot chute inflates 27 m behind the DM and pulls the Back Cover away from the rest of the assembly. As it goes, the Back Cover pulls the 8.30 m-diameter DGB main parachute from its container. This canopy inflates during the supersonic phase to decelerate and stabilise the Probe through the transonic region. The Front Shield is released at about Mach 0.6. In fact, the main parachute is sized by the requirement to provide sufficient deceleration to guarantee a positive separation of the Front Shield from the Descent Module.

The main parachute is too large for a nominal descent time shorter than 2.5 h, a constraint imposed by battery limitations, so it is jettisoned and a 3.03 m-diameter DGB stabilising parachute is deployed. All parachutes are made of Kevlar lines and nylon

Figure 2. Huygens parachute deployment sequence



fabric. The main and stabiliser chutes are housed in a single canister on the DM's top platform. A swivel using redundant low-friction bearings in the connecting riser of both the main and stabiliser chutes ensures that the lines do not tangle as the Probe spins.

Separation Subsystem (SEPS)

SEPS provides: mechanical and electrical attachment to, and separation from, the Orbiter; the transition between the entry configuration ('cocoon') and the descent configuration (DM under parachute). The three SEPS mechanisms are connected on one side to Huygens' Inner Structure (ISTS) and on the other to the Orbiter's supporting struts. As well as being the Probe-Orbiter structural load path, each SEPS fitting incorporates a pyro-nut for Probe-Orbiter separation, a rod cutter for Front Shield release, and a rod cutter for Back Cover release.

Within SEPS, the Spin Eject Device (SED) performs the mechanical separation from the

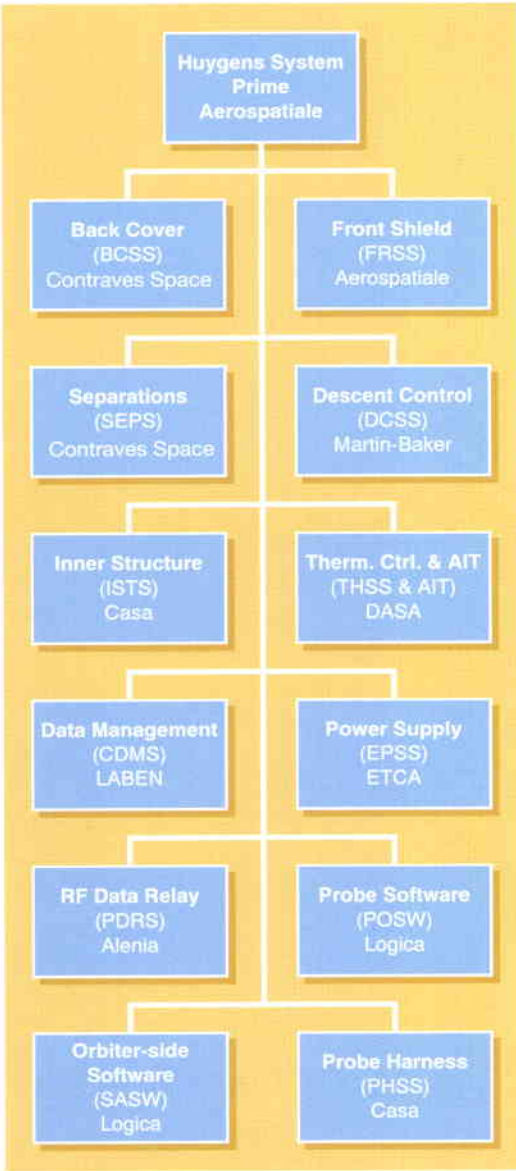


Figure 3. Geographical distribution of the Huygens Probe industrial responsibility

- Orbiter:
- three stainless steel springs provide the separation force
 - three guide devices, each with two axial rollers running along a T-profile helical track, ensure controlled ejection and spin, even in degraded cases such as high friction or a weak spring
 - a carbon-fibre ring accommodates the asymmetrical loads from the Orbiter truss and provides the necessary stiffness before and after separation
 - three pyro-nuts provide the mechanical link before separation.

In addition, the Umbilical Separation Mechanism of three 19-pin connectors, which provide Orbiter-Probe electrical links, is disconnected by the SED.

Inner Structure Subsystem (ISTS)

The ISTS provides mounting support for the Probe's payload and subsystems. It is fully sealed except for a vent hole of about 6 cm² on the top, and comprises:

- the 73 mm-thick aluminium honeycomb sandwich Experiment Platform, which supports the majority of the experiments and subsystems units, together with their associated harness
- the 25 mm-thick aluminium honeycomb sandwich Top Platform, which supports the Descent Control Subsystem and Probe RF

Figure 4. The organisation of the Huygens industrial consortium

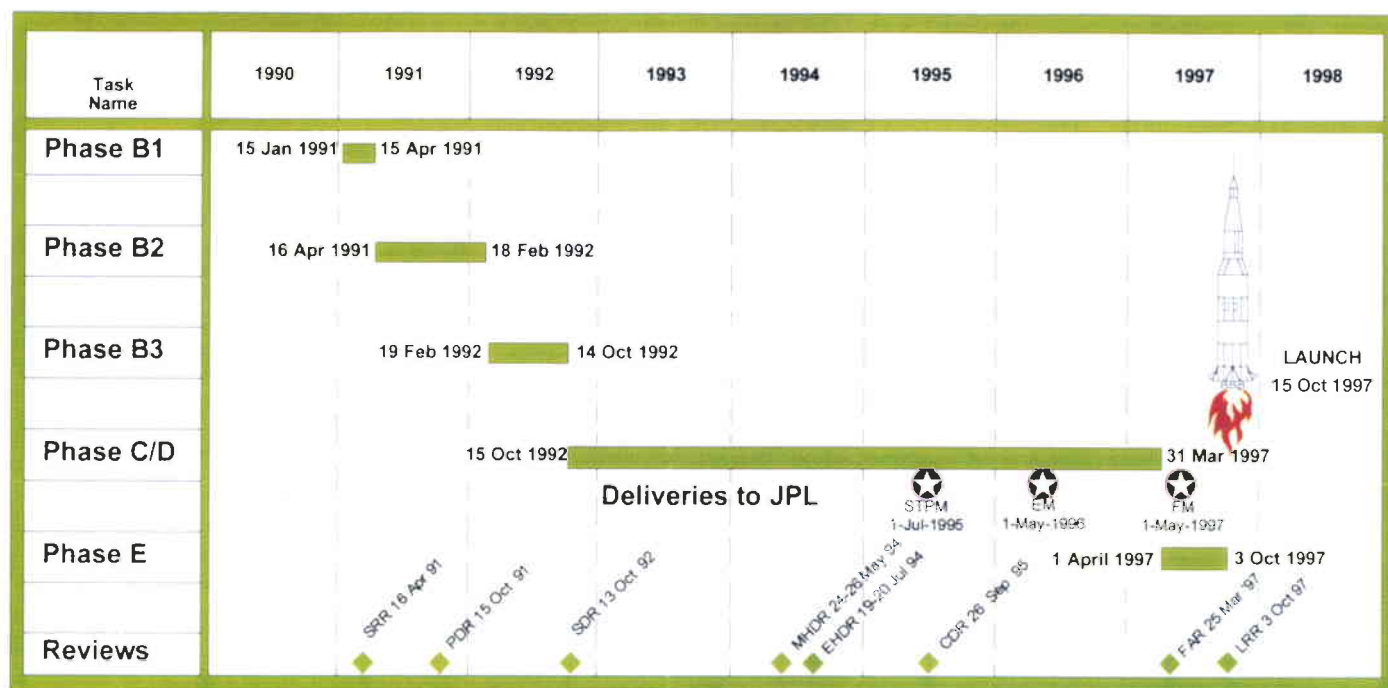
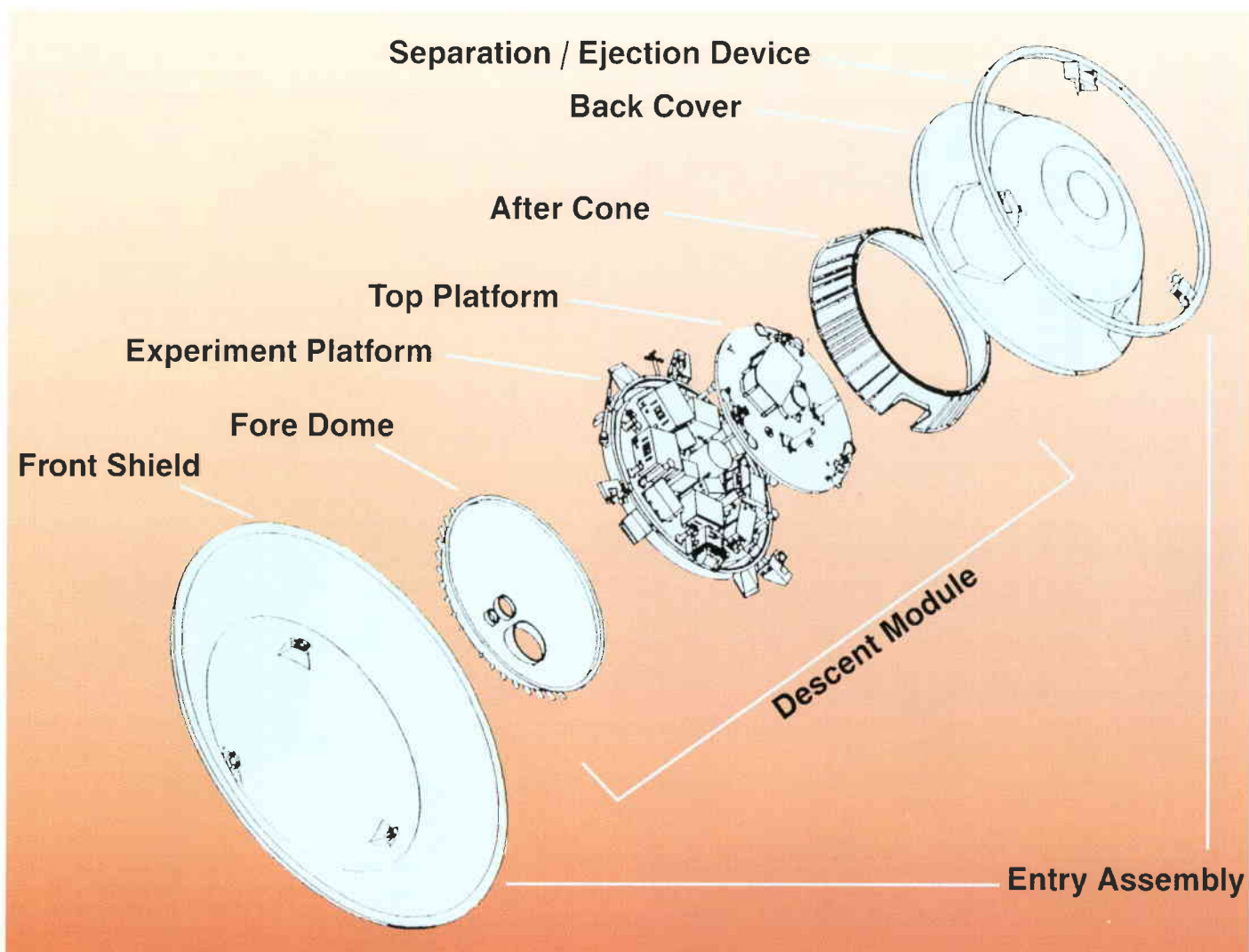


Figure 5. The Huygens project overall development schedule

SRR: System Requirement Review; PDR: Preliminary Design Review; SDR: System Design Review; MHDR: Mechanical Hardware Design Review; EHDR: Electrical Hardware Design Review; CDR: Critical Design Review; FAR: Flight Acceptance Review; LRR: Launch Readiness Review

Figure 6. Huygens consists of the Descent Module (DM) within the Entry Assembly (ENA)



- antennas, and forms the DM's top external surface
- the After Cone and Fore Dome aluminium shells, linked by a central ring
- three radial titanium struts, which interface with SEPS and ensure thermal decoupling, while three vertical titanium struts link the two platforms and transfer the main parachute deployment loads
- 36 spin vanes on the Fore Dome's periphery, which provide a controlled spin rate during descent
- the secondary structure, for mounting experiments and equipment.

Thermal Subsystem (THSS)

While the PSE is thermally controlled by the Orbiter, the Probe's THSS must maintain all experiments and subsystem units within their allowed temperature ranges during all mission phases. In space, the THSS partially insulates the Probe from the Orbiter and ensures that there are only small variations in the Probe's internal temperatures, despite the incident solar flux varying from 3800 W/m^2 (near Venus) to 17 W/m^2 (approaching Titan after 22 days of the coast phase following Orbiter separation).

As shown in Figure 10, Probe thermal control is achieved by:

- MLI covering all external surfaces, except for the small 'thermal window' (see below) of the Front Shield
- 35 Radioisotope Heater Units (RHUs) on the Experiment and Top Platforms, each continuously providing about 1 W even when the Probe is dormant

- a white-painted 0.17 m^2 , thin aluminium sheet on the Front Shield's forward face acting as a controlled heat leak (about 8 W during cruise) to reduce the sensitivity of thermal performances to MLI efficiency.

The MLI is burned and torn away during entry, leaving temperature control to the AQ60 high-temperature tiles on the Front Shield's front face, and to Prosial on the Front Shield's aft surface and on the Back Cover.

During the descent phase, thermal control is provided by foam insulation and gas-tight seals. Lightweight open-cell Basotect foam covers the internal walls of the DM's shells and Top Platform. This prevents convection cooling by Titan's cold atmosphere (70 K at 45 km altitude) and therefore thermally decouples the units mounted on the Experiment Platform from the cold aluminium shells. Gas-tight seals around all elements protruding through the DM's shell minimise gas influx. In fact, the DM is gas tight except for a single 6 cm^2 hole in the Top Platform that equalises pressure during launch and the descent to Titan's surface.

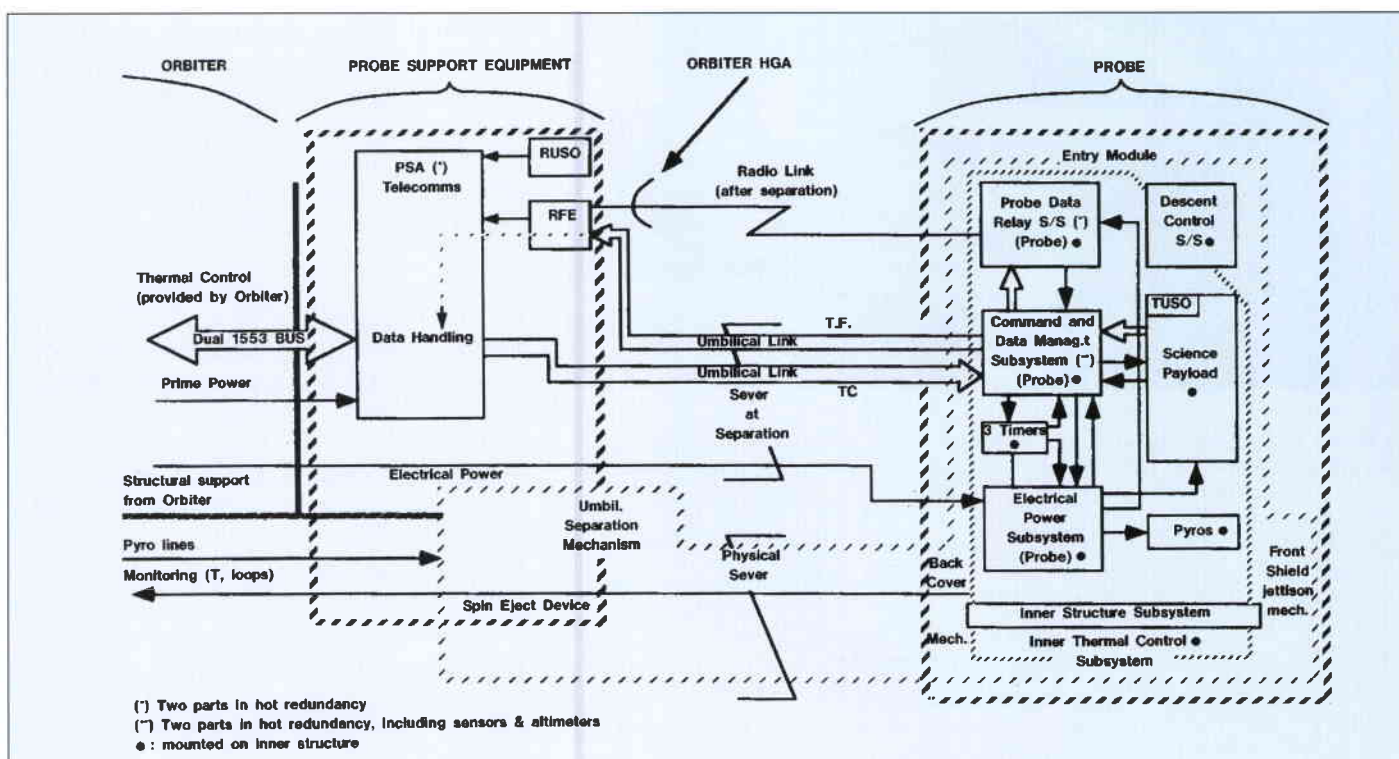
Electrical Power Subsystem (EPSS)

The EPSS consists of:

Five batteries, which provide power from the time of Orbiter separation until at least 30 min after arrival on Titan's surface. Each battery comprises two modules of 13 LiSO_2 (7.6 Ah) cells in series.

A Power Conditioning & Distribution Unit (PCDU), which provides the power conditioning

Figure 7. Huygens Probe system architecture
PSA: Probe System Avionics; S/S: subsystem; TUSO: Transmitter Ultra Stable Oscillator; RUSO: Receiver Ultra Stable Oscillator; HGA: High Gain Antenna; RFE: Receiver Front End; TF: Transfer Frame



and distribution to the Probe's equipment and experiments via a regulated main bus, with protection to ensure uninterrupted operations even in the event of single failures inside or outside the PCDU.

During the cruise phase, the Probe is powered by the Orbiter and the PCDU isolates the batteries. The five interface circuits connected to the Orbiter's Solid-State Power Switches (SSPSs) provide Probe-Orbiter insulation and voltage adaptation between the SSPS output and the input of the PCDU's Battery Discharge Regulator (BDR) circuits. The BDRs condition the power from either the Orbiter or the batteries and generate the 28 V bus, controlled by a centralised Main Error Amplifier (MEA). The distribution is performed by active current limiters, with the current limitation adapted for each user and with an on/off switching capability.

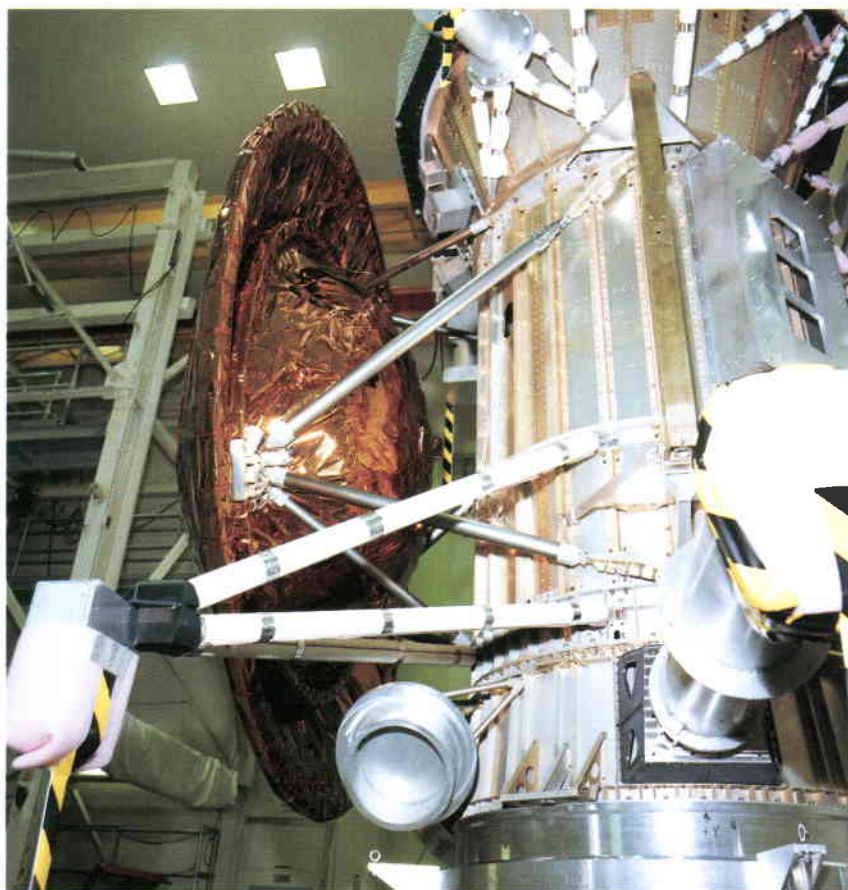


Figure 8. Huygens Probe accommodation on the Cassini Orbiter

The Mission Timer, however, is supplied by three switchable battery voltage lines through series fuses or, when the PCDU is powered by the Orbiter, by dedicated output voltage lines of the Orbiter interface circuits.

The PCDU also provides a protected +5 V supply used by the Pyro unit to generate the bi-level status telemetry of the selection relays and for the activation circuit that switches on the Pyro unit's energy intercept relay.

A *Pyro Unit (PYRO)* provides two redundant sets of 13 pyro lines, directly connected to the centre taps of two batteries (through protection devices), for activating pyro devices. Safety requirements are met by three independent levels of control relays in series in the Pyro Unit, as well as active switches and current limiters controlling the firing current. The three series relay levels are: energy intercept relay (activated by PCDU at the end of the coast phase); arming relays (activated by the arming timer hardware); selection relays (activated by Command and Data Management Unit, CDMU, software). In addition, safe/arm plugs are provided on the unit itself for ground operations.

EPSS operational modes

Cruise phase

The EPSS is completely off over the whole cruise phase, except for periodic checkout operations. There is no power at the Orbiter interface and direct monitoring by the Orbiter allows verification that all the relays are open and that the PCDU temperature (representative of all units within the inert Probe) is within limits.

Cruise phase checkout

The EPSS is powered by the Orbiter for cruise checkout operations. The 28 V bus is regulated by the EPSS BDRs associated with each Orbiter SSPS; a total of 210 W is available from the Orbiter. All of the relays remain open during the check-out.

Timer loading

Following the loading (from the Orbiter) of the correct coast-time duration into the Mission Timer Unit, battery depassivation is performed to minimise any energy loss due to ageing of the chemically active surfaces within the battery during cruise. Before Probe separation, the EPSS timer relays are closed to supply the Mission Timer from the batteries and the Orbiter power is switched off.

Coast phase

Only the Mission Timer is supplied by batteries through specific timer relays during the coast phase. The EPSS is off and all other relays are open.

End of coast phase — Probe wake-up

At the end of the coast phase, the Mission Timer wakes the Probe by activating the EPSS. Input relays are closed and the current limiters powering the CDMU are automatically switched on as soon as the 28 V bus reaches its nominal value (other current limiters are initially off at power up). The pyro energy intercept relay is also automatically switched on by a command from the PCDU.

HUYGENS Subsystems



Entry and descent phases

All PCDU relays are closed and the total power (nominal 300 W, maximum 400 W) is available on the 28 V distribution outputs to subsystems and equipment. The Pyro Unit performs the selection and the firing of the pyros, activated by CDMU commands.

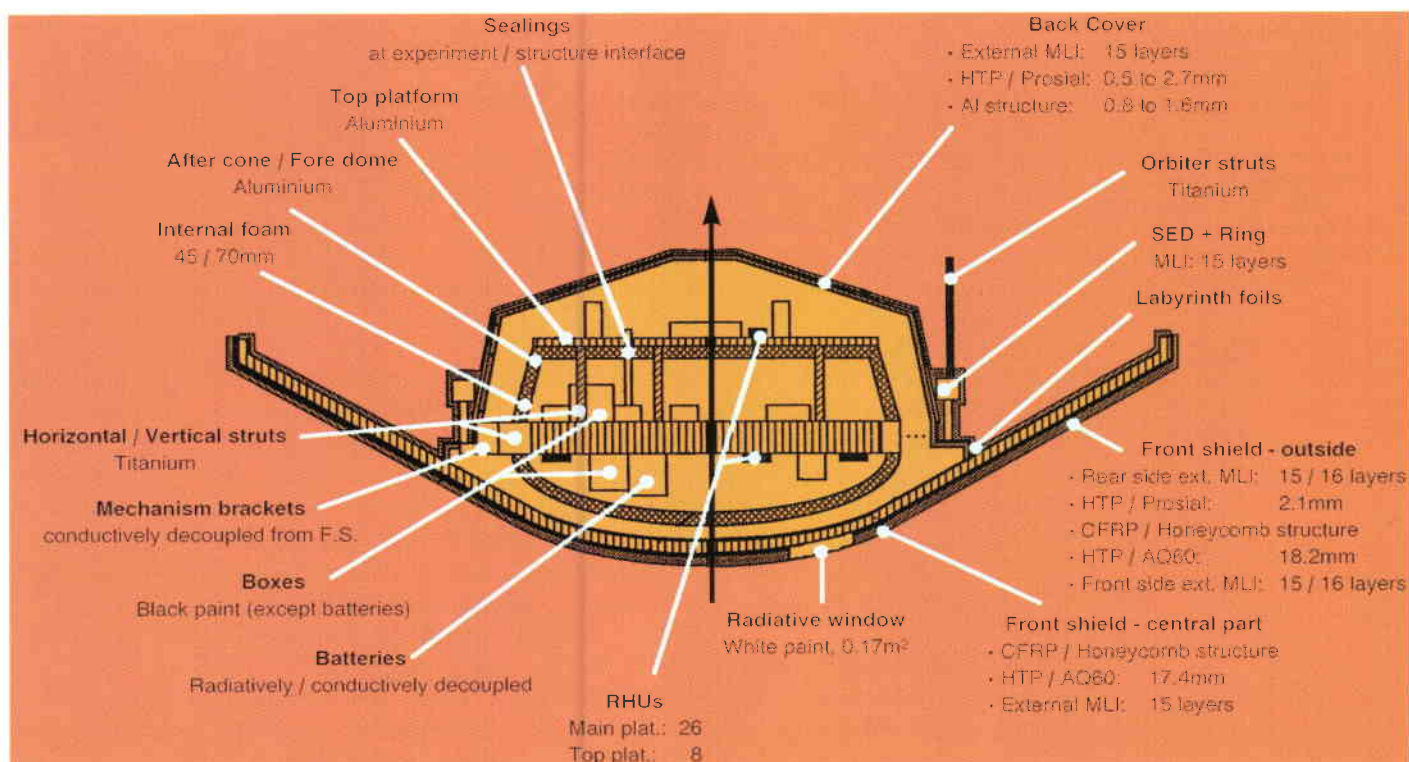
Probe Data Relay Subsystem (PDRS)

The PDRS (Fig. 12) is Huygens' telecom-

munications subsystem, combining the functions of RF link, data handling and communications with the Orbiter. It transmits science and housekeeping data from the Probe to the Orbiter-mounted PSE, which are then relayed to the Orbiter CDS via a Bus Interface Unit. In addition, the PDRS is responsible for telecommand distribution from the Orbiter to the Probe by umbilical during the ground and cruise checkouts. The PDRS comprises:

Figure 9. Huygens Probe subsystem breakdown

Figure 10. The Probe's thermal control system
RHU: Radioisotope Heater Unit; MLI: Multi-Layer Insulation



- two hot-redundant S-band transmitters and two circularly polarised Probe Transmitting Antennas (PTAs) on the Probe
- a Receiver Front End (RFE) unit (enclosing two Low-Noise Amplifiers and a diplexer) and two Probe Support Avionics (PSA) units on the Orbiter.

The Orbiter's High Gain Antenna (HGA) acts as the PDRS receive antenna.

In addition, as part of the Doppler Wind Experiment (DWE), two ultra-stable oscillators are available as reference signal sources to allow the accurate measurement of the Doppler shift in the Probe-Orbiter RF link: the

EOM, respectively). At BOM, the signal level is determined by the range, while the losses owing to off-axis pointing are mainly due to HGA pointing and Probe delivery errors (the additional dispersion arising from variations in the entry phase is relatively minor). At EOM, however, the signal level is critically dependent on the descent duration: the off-axis pointing losses due to the Probe's lateral drift in the assumed Titan wind worsens with the longer descent duration.

Command and Data Management Subsystem (CDMS)

The CDMS has two primary functions: autonomous control of Probe operations after separation, and management of data transfer from the equipment, subsystems and experiments to the Probe transmitter for relay to the Orbiter. The data are stored redundantly on the Orbiter's two Solid-State Re-records (SSRs) for subsequent downlinking to Earth when the Orbiter has been reoriented to its normal attitude with its HGA Earth-pointing. (During cruise checkouts, this attitude allows direct data downlinking if NASA Deep Space Network (DSN) coverage is available.)

The driving requirement of the CDMS design is intrinsic single-point-failure tolerance. As a result of the unusual Huygens mission (limited duration and no access by telecommand after separation), a very safe redundancy scheme has been selected. As shown in Figure 11, the CDMS therefore comprises:

- two identical CDMUs
- a triply redundant Mission Timer Unit (MTU)
- two mechanical *g*-switches (backing up MTU)
- a triply redundant Central Acceleration Sensor Unit (CASU)
 - two sets of two mechanical *g*-switches (backing up CASU)
 - a Radial Acceleration Sensor Unit (RASU) with two accelerometers
 - two Radar Altimeter proximity sensors, each comprising separate electronics, transmit antenna and receive antenna.

The two CDMUs each execute their own POSW simultaneously and are configured with hot redundancy (Chain A and Chain B). Each hardware chain can run the mission independently. They are identical in almost all respects, with the following minor differences facilitating simultaneous operations and capitalising on the redundancy:

- telemetry is transmitted at two different RF frequencies
- Chain B telemetry is delayed by about 6 s to avoid loss of data should a temporary loss of the telemetry link occur (e.g. due to an

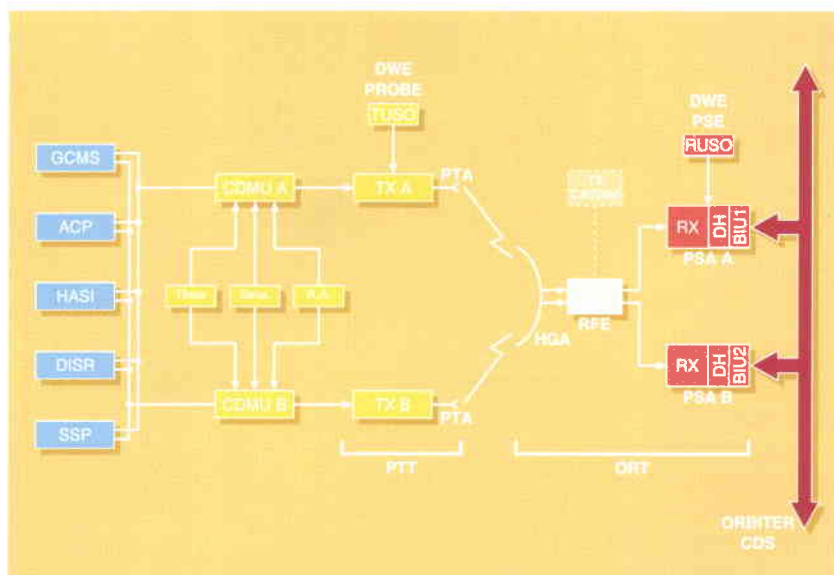


Figure 11. The Probe's Command and Data Management Subsystem (CDMS)

CASU: Central Acceleration Sensor Unit; CDMU: Command and Data Management Unit; HASI: Huygens Atmospheric Structure Instrument; I/F: intermediate frequency; PSA: Probe Support Avionics; RASU: Radial Acceleration Sensor Unit; TC: Telecommand; TM: Telemetry

Transmitter Ultra Stable Oscillator (TUSO) on the Probe and the Receiver Ultra Stable Oscillator (RUSO) on the Orbiter.

The PDRS electrical architecture is fully channelised for redundancy, except that TUSO and RUSO are connected to only one chain. During Probe descent, starting from the time of atmospheric entry as predicted from Orbiter trajectory and Probe separation characteristics, the Orbiter HGA is controlled to track a fixed point on Titan's surface — the nominal touchdown point. Orbiter movement along its trajectory significantly reduces the 'space loss' due to link distance during the Probe's 2-2.5 h descent. However, if Huygens does not land at the nominal point, e.g. due to non-nominal entry parameters or zonal winds, the gain in received signal strength arising from the reduced distance is offset by the HGA's reduced gain due to the off-axis angle of the Probe with respect to the HGA's boresight axis.

The link budget worst cases occur at the beginning and end of mission. The link design attempts to equalise the signal-level margins at the Beginning and End of Mission (BOM and

antenna misalignment if the Probe oscillates excessively beneath the parachute).

Each CDMU chain incorporates a health check (called the Processor Valid status), which is reported to the experiments in the Descent Data Broadcasts (DDBs). Either chain will declare itself invalid when two bit errors in the same memory word, an ADA exception, or an under-voltage on the 5 V line occur within the CDMU.

Software

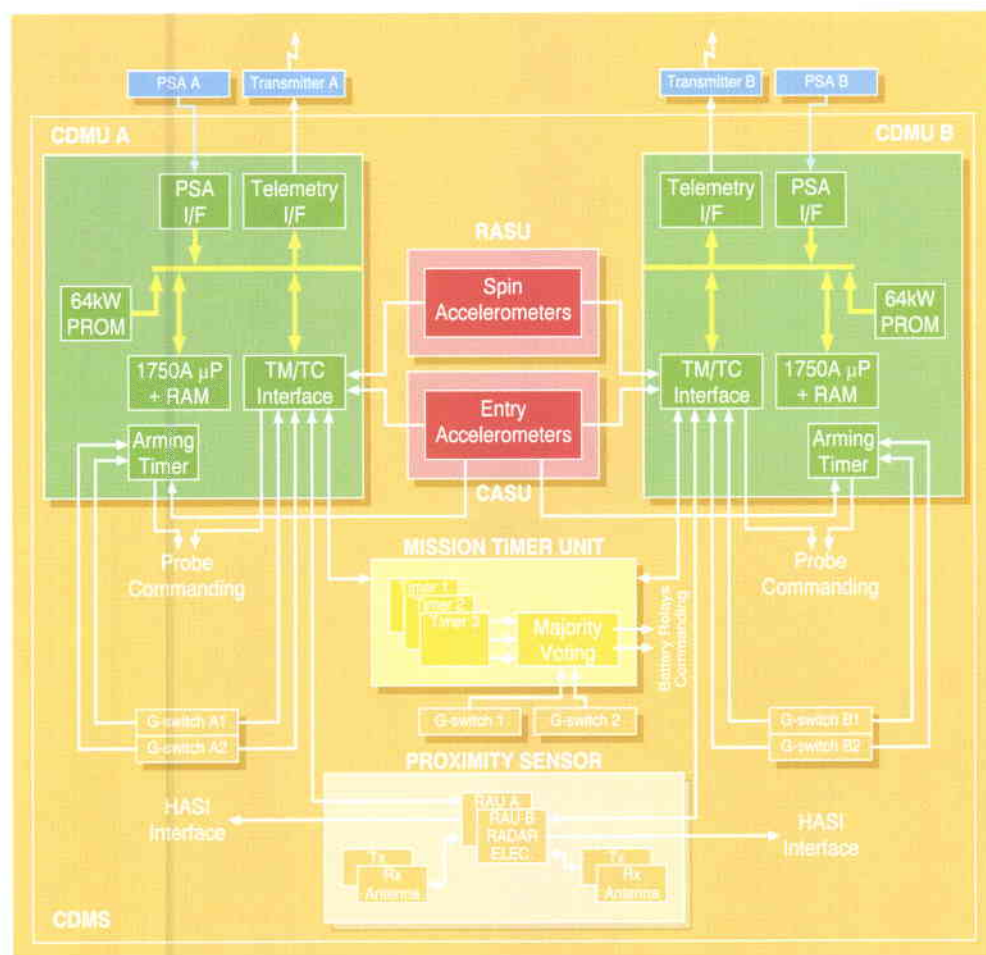
The Huygens software consists of that running in the Probe CDMS, referred to as Probe Onboard Software (POSW), and that within the PSA on the Orbiter, referred to as the Support Avionics Software (SASW). The POSW output telemetry is relayed via the SASW and then Cassini's CDS to the ground. The redundant data handling hardware (CDMU's and PSA's) run identical copies of POSW and SASW.

The software is based on a top-down hierarchical and modular approach using the Hierarchical Object-Oriented Design (HOOD) method and, except for some specific low-level modules, is coded in ADA. The software consists, as much as possible, of a collation for synchronous processes timed by a hardware reference clock (8 Hz repetition rate). In order to avoid unpredictable behaviour, interrupt-driven activities are minimised. Such a design also provides for better software observability and reliability.

The processes are designed to use data tables as much as possible. Mission profile reconfiguration and experiment polling can therefore be changed only by reprogramming these tables. This is possible via an EEPROM. In order to avoid a RAM modification while the software is running (which can lead to unpredictable behaviour and unnecessary complexity), direct RAM patching is forbidden.

The POSW communicates with the SASW in different ways depending on the particular mission phase. Before Probe separation, the two software subsystems communicate via an umbilical that provides both command and telemetry interfaces. Huygens cannot be commanded after separation, and telemetry is transmitted to the Orbiter via the PDRS RF link. The overall operational philosophy is that the

software runs the nominal mission from power-up without checking its hardware environment or the Probe's connection or disconnection. The specific software actions or inhibitions required for ground or flight checkout must therefore be invoked by special procedures, activated by the delivery of specific telecommands to the software.



To achieve this autonomy, POSW's in-flight modification is autonomously applied at power-up by using a non-volatile EEPROM. At power-up, the POSW validates the CDMU EEPROM structure and then applies any software patches stored in the EEPROM before running the (resultant) software. If the EEPROM proves to be invalid at start-up, no patches are applied and the software continues based on the software in the CDMU ROM. A number of other checks are also carried out at start-up (e.g. a DMA check and a main ROM checksum), but the software will continue execution attempts even if the start-up checks fail.



Figure 12. The Probe Data Relay Subsystem (PDRS)
ACP: Aerosol Collector and Pyrolyser; CDMU: Command and Data Management Unit; DISR: Descent Imager/Spectral Radiometer; DWE: Doppler Wind Experiment; GCMS: Gas Chromatograph Mass Spectrometer; HASI: Huygens Atmospheric Structure Instrument; LNA: Low-Noise Amplifier; ORT: Orbiter Receiving Terminal; PTA: Probe Transmitting Antenna; PTT: Probe Transmitting Terminal; RA: Radar Altimeter; SSP: Surface Science Package



Huygens Probe Mission Flight Operations*

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Introduction

Cassini will take 6.7 years to reach Saturn before Huygens is released into Titan's atmosphere and the Orbiter begins a four-year orbital tour of the planet, rings, satellites and magnetosphere. NASA's Jet Propulsion Laboratory (JPL) will control the Orbiter, whereas the Probe is ESOC's responsibility. The data exchange between Huygens and the HPOC – telecommands and telemetry – will be routed via the Cassini Mission Support Area (MSA) at JPL using NASA's Deep Space Network (DSN) facilities.

The Cassini/Huygens Ground System is designed to meet all the requirements of operating the combined mission under a 160 min round-trip light time (at Probe separation), with high reliability and within critical resource budgets, over a period of more than 10 years. It allows both flight control teams to manage the mission and to cope with its particular constraints and characteristics, especially those arising from the impossibility of having real-time interaction with the spacecraft and from the autonomous nature of many of the onboard systems.

Huygens is being carried as a passenger on NASA's Cassini Orbiter to Saturn, where it will be released to enter the atmosphere of Titan, the planet's largest moon. During the controlled descent phase, its instruments will execute a complex sequence of measurements to study the atmosphere's chemical and physical properties and, if it survives impact, Huygens will collect data on Titan's surface properties. Flight operations will be conducted from the Huygens Probe Operations Centre (HPOC) at ESOC. This article describes the ground-system infrastructure, procedures and constraints involved in operating Huygens over its 6.7-year mission lifetime.

The Huygens mission

Some 73 days after the Saturn orbit insertion burn of 1 July 2004, an Orbiter trajectory manoeuvre raises periapsis and targets the combined spacecraft for Titan impact. Huygens is released 22 days before the first Titan flyby on 27 November 2004. Two days later, the Orbiter performs a deflection manoeuvre to pass over the Probe's landing site. It then points its high-gain antenna at the predicted touchdown point to receive descent telemetry data and store it redundantly on two solid-state recorders. During its coast to Titan, Huygens is essentially dormant, with only a timer running. Twenty-four minutes before the predicted atmospheric entry, this timer triggers a sequence that applies power to the Probe subsystems and scientific instruments. The parachute-controlled descent through the atmosphere is initiated by a complex series of events driven by three redundant accelerometers, in a majority-voting configuration, monitoring deceleration as an indicator of Mach number. Pyrotechnic devices release the front shield and back cover, and a pilot parachute pulls out the main parachute. Subsequent events are triggered by a software timer, initiated at the moment of parachute release,

Cassini/Huygens mission operations will be carried out from these two centres, working in close liaison. Both spacecraft will be operated largely through pre-programmed, time-driven command sequences, either uplinked from the ground or activated by onboard software. After separating from Cassini, Huygens has no telecommand capability and so during the descent through Titan's atmosphere the operation of its scientific instruments is entirely automatic, driven by a combination of triggered and programmable schedules. To ensure mission success, all Probe systems are hot-redundant and their performances are checked out, up to Probe release, at regular intervals throughout the cruise to Saturn.

*This article is an abbreviated version of the paper by C. Sollazzo et al. in *Huygens: Science, Payload and Mission*, ESA SP-1177, August 1997

T_0 . These events include establishing the radio relay, switching on further instruments and replacing the parachute with a smaller drogue to ensure that Huygens reaches the surface within 150 min. The descent time is constrained by the capacity of the Probe's batteries and by the changing geometry of the relay link as the Orbiter continues in its orbit about Saturn.

Critical functions such as pyrotechnics, which could endanger the mission if executed prematurely, are protected by an independent hardware timer that is initiated at a higher deceleration value a few seconds before T_0 . The instruments control their operations using information about time and predicted or measured altitude broadcast to them from the Probe command and data management subsystem. During checkouts, these operations are activated from a simulated T_0 , but in the absence of deceleration the arming sequence is not run.

Should Huygens survive the impact with the solid or liquid surface, it continues to transmit data until the batteries are exhausted and these data are recorded by the Orbiter until 30 min after the latest predicted touchdown. Later, the Orbiter is reoriented to transmit those recorded data to the Cassini Ground System. The Huygens Flight Control Team then transfers the data to the HPOC at ESOC. The Probe telemetry data is retained by the Orbiter until successful downlinking is confirmed.

Mission operations

Owing to the long propagation delays to be expected during most of the Cassini mission (up to 160 min round-trip light time), real-time monitoring and control looping – common for most near-Earth missions – are not feasible. A

more suitable approach is that of uplinking a set of time-tagged commands every two months for subsystems, scientific payload and Huygens, covering all of the operational activities that must be performed during that time. These sets constitute the Sequence Programs, stored and executed by the Orbiter's Command and Data Subsystem (CDS).

To simplify the mission planning and sequence generation process, the mission is planned using 'operational modes' (i.e. power and data-rate resource envelopes applied to the operational states of the spacecraft subsystems and scientific instruments) and a limited number of 'unique' sequences. The spacecraft is always controlled through an operational mode, a unique sequence, or a pre-defined transition between operational modes.

All Probe activities are designed as 'unique' sequences. The Probe relay sequence is defined to be a 'critical' sequence in order to ensure that even an Orbiter fault condition does not prematurely terminate the relay sequence. The planning and generation of any Probe checkout, the release and the relay sequences is a coordinated effort between Cassini's uplink operations team at JPL and the Huygens operations team at ESOC. Figure 1 illustrates the process for scheduling, generating, validating and radiating sequencing programs to the Orbiter's control and data management system to control Probe activities.

The long-range mission planning activities began about a year before launch. These consist of the analysis and coordination necessary to identify the major engineering, scientific and Probe activities necessary to achieve the mission plan, based on the latest

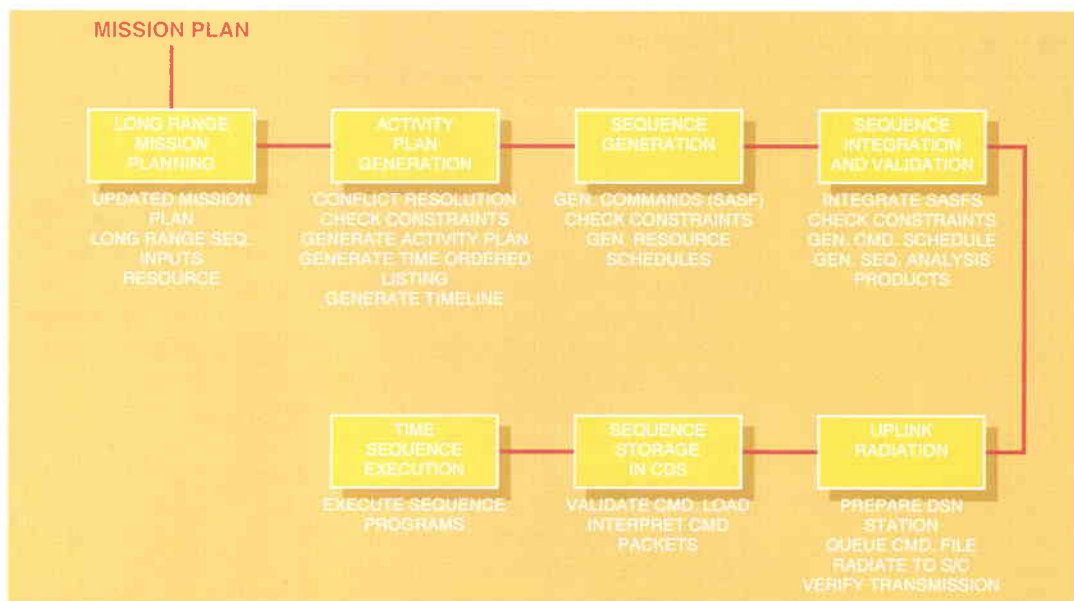


Figure 1. Cassini uplink planning and generation process
 SASF: Spacecraft Activity Sequence File
 CDS: Command and Data Subsystem
 DSN: Deep Space Network

trajectory data and related ground-support activities. Thereafter, the mission planning process for any given Probe activity begins about 8 weeks before the uplinking of the sequence containing that activity, and takes about 3 weeks to complete. After the mission plan has been updated to include the new activities, an activity plan is produced. During this process, which takes about 2 weeks, all conflicts are resolved and spacecraft activity sequence files are generated that specify the start and stop times of spacecraft activities.

During the sequence generation process, which lasts about seven working days, the activity plan serves as a basis for generating activity files at the command level. For a particular Probe activity, it includes Probe telecommands (which include instrument commands) submitted by Huygens operations personnel, and Orbiter commands submitted by Cassini operations personnel. The sequence integration and validation process, which lasts about 11 working days, integrates all the activity files that have been generated for a particular sequence.

Upon sequence validation and approval, the final Ground Command File is generated and queued at the station and radiated to the spacecraft. Upon uplink validation by the Orbiter CDS, the sequence programs are registered and sequence execution is allowed to commence.

The Cassini ground system performs the primary functions of mission planning and navigation, spacecraft command and control, spacecraft data acquisition, information processing and storage, and data distribution and archiving. These tasks are performed with the aid of a network of workstations interconnected via the Cassini local area networks (LANs). Figure 2 illustrates the interface connection between the facilities at ESOC and those at JPL. A Cassini Science Operations Planning Computer (SOPC) workstation is installed at ESOC as a gateway to the Cassini LANs.

Huygens mission operations

During the cruise phase, a full Probe checkout about every six months verifies that no Probe failures or calibration changes have developed. The checkout data are analysed by the operations team and the Probe scientific calibration or simulated mission data are distributed to the instruments' Principal Investigators for their own processing and analysis. Any contingencies arising in a given checkout period are analysed between checkout periods and any reaction and

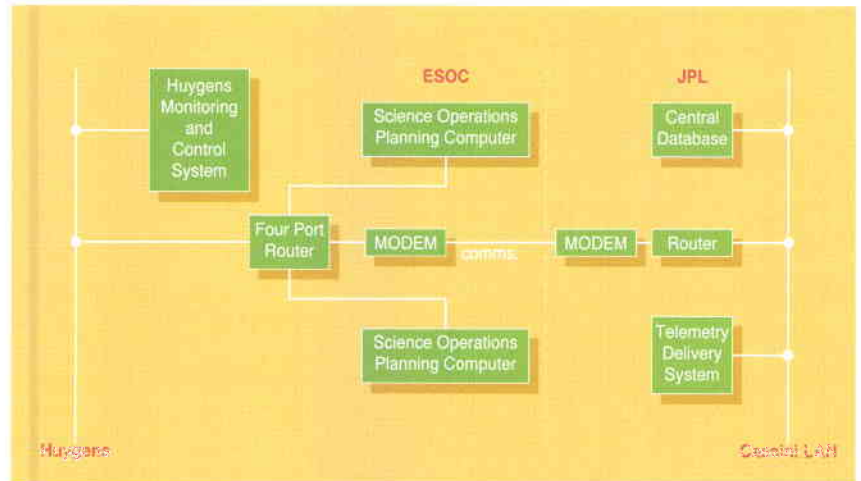


Figure 2. The ESOC/JPL interface

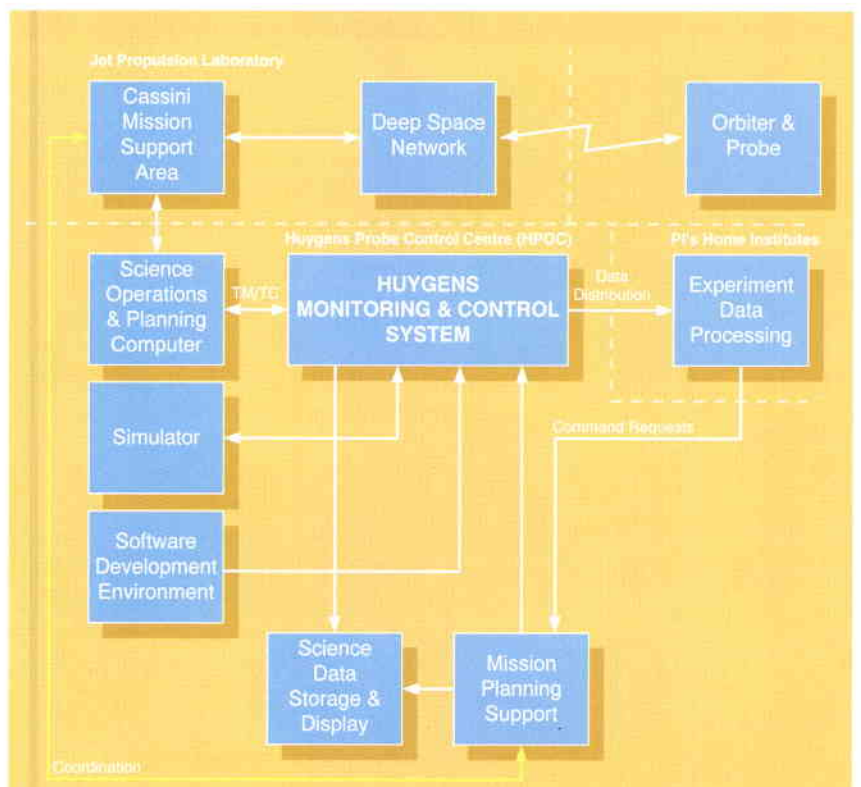
corrective action is attempted during the next checkout. Recovery activities principally involve modifications to the Probe or instrument onboard software.

During the Saturn orbit phase (July to November 2004), all Probe subsystems and instruments are brought into their final configuration to perform the automatic descent sequence of operations, during a series of Probe checkout periods. Telecommanding is impossible once the Probe is released and from this moment on the Probe follows the automatic sequence of events programmed into the onboard software that drives its activities until the end of the mission.

The Probe Operations Centre

The functional breakdown of the HPOC is as follows (Fig. 3):

Figure 3. Overview of the Huygens Probe Operations Centre (HPOC) functionalities

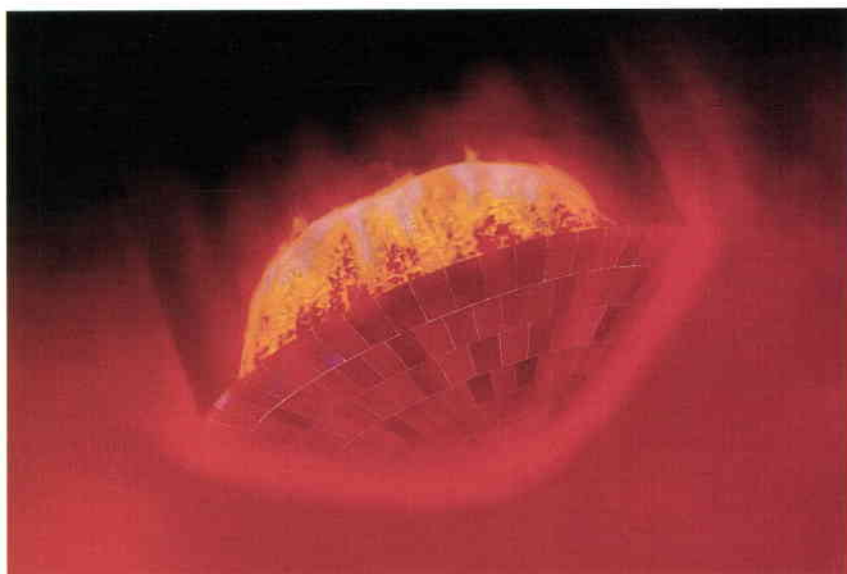


The *Huygens Monitoring and Control System (HMCS)* provides the ground data processing facilities and interface support needed for proper execution of the Probe operations and the distribution of mission products to the external users involved.

The *Science Operations and Planning Computer (SOPC)* is the gateway for all operational data exchange between ESOC and JPL.

The *Science Data Storage and Display* is used by the Principal Investigators to analyse and display the mission scientific data collected during the Saturn orbit and descent phases.

The *Mission Planning Support* is responsible for defining, planning and validating any Probe operations needed.



There are also operational *Interfaces* with: *JPL* for the uplink and downlink functions, as well as for overall mission coordination; *Principal Investigators' Home Institutes* for scientific data distribution and instrument operations command inputs.

Also part of HPOC, and functionally closely related to the mission planning support, are the: *Probe Simulator*, which is the primary validation tool for operational procedures and onboard software design (it is also used for training the flight control team), and the *Onboard Software Development Environment (SDE)* needed to develop/maintain the onboard software and to validate new or modified software at subsystem level, before creating the relevant software update procedures, which in turn are validated at system level by using the Probe Simulator.

The Probe operation process

Power for the checkouts is provided by the

Orbiter during the cruise and Saturn orbiting phases. During these phases, when the Probe is controllable from the ground by telecommand, carefully designed command sequences test the health of the Probe and instruments, and perform either a simulated descent sequence or special instrument calibrations.

The Probe is designed to perform its mission (the descent to Titan) automatically, with all activities driven by the onboard software based on a set of tables pre-defined for producing the 'best' mission output in the both the nominal and failure cases. The checkout is designed to demonstrate that the subsystems and instruments are completely healthy and able to support the mission.

Several months may elapse between the preparation of the command sequence for a given checkout and the actual reception and analysis of the telemetry data. As mentioned earlier, a finalised Probe command sequence for a given checkout period will usually be transmitted to JPL two months before its execution time. It may then take up to a week after the checkout execution before a suitable DSN pass can be used for downlinking the Probe-produced telemetry. All of the operational activities must be defined and properly planned with these constraints in mind: the planning and generation of any Probe checkout and of the final Probe release/data relay sequence is a coordinated effort between the Orbiter and Huygens operations teams.

Probe cruise operations

The Probe checkout operations sequence can be modified by ESOC as required. It may be routine, but some anomalous Probe or instrument behaviours might have to be analysed and resolved. In principle, the functional sequence described below applies to all the checkout periods, including that for pre-separation, although here there are some additional activities.

The preparation activities define the checkout objectives and how to achieve them. This includes any special requests of operations for any instrument, as well as operational activities related to the investigation and solution of possible contingencies arising from onboard anomalies in the Probe, Probe Support Equipment (PSE, on the Orbiter) or instruments. To achieve the most efficient use of the checkout periods allocated to the Probe in the Cassini Mission Plan, the following inputs are needed at $T_{up}-3$ months (where T_{up} is the uplink time of the Cassini telecommand sequence): *Cassini Mission Planning*: Contains the

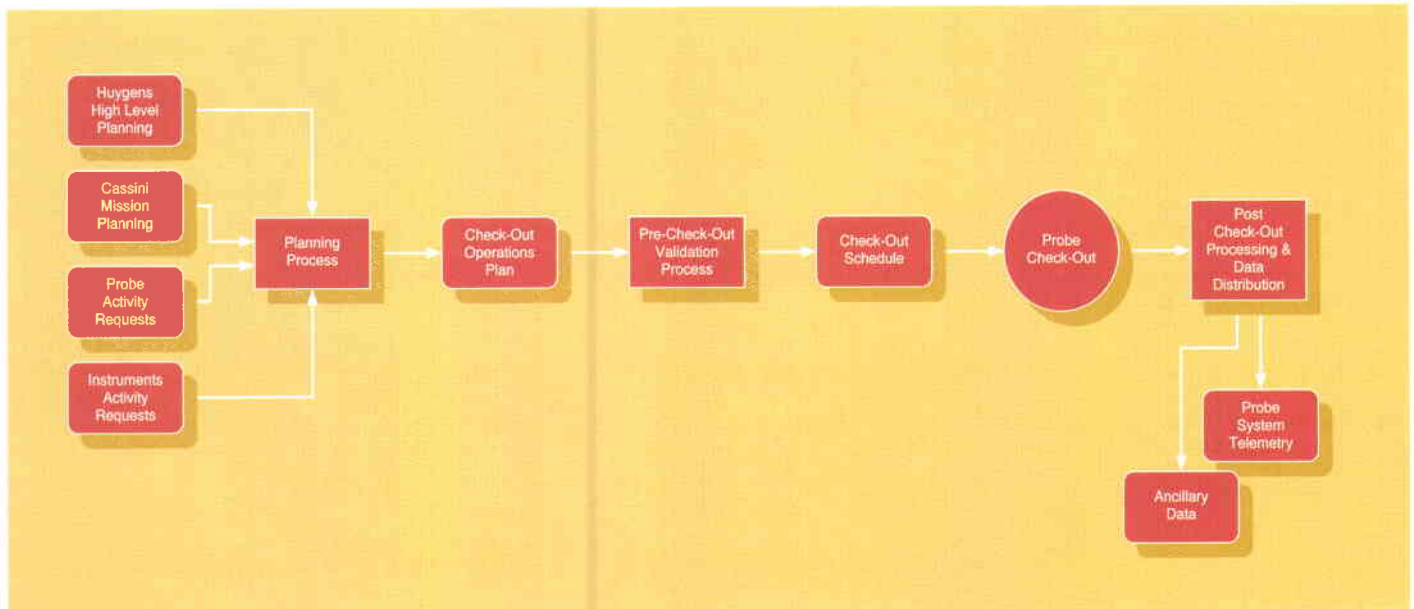


Figure 4. The cruise-phase checkout activities

operations plan for the Orbiter around the time of the checkout, needed for coordination purposes with JPL.

Probe Activity Requests: Contain any requests for operations to be performed during the applicable checkout period.

Instrument Activity Requests: Contain any requests for special operations on the onboard instruments to be performed during the applicable checkout period.

The checkout operations sequence is illustrated in Figure 4:

- T_{up}-2.5 months: A checkout operations plan for the period in question is prepared based on the above data. The relevant command schedules are produced from the checkout operations plan and validated by simulation at the subsystem and system levels.
- T_{up}-2 months: The finalised telecommand schedules are converted into Spacecraft Activity Sequence Files (SASFs) and made available to the Cassini Data Processing Center.
- JPL then merges the Huygens activity sequences into an overall Orbiter spacecraft sequence file. This file is validated by ESOC, for the part relevant to the Probe, and a 'go /no-go' decision to uplink is taken.
- Once the command sequence has been forwarded to the Probe for execution, the generated telemetry is routed to the Orbiter for relay to the Mission Support Area for archiving.
- As soon as possible, ESOC accesses the JPL Cassini Data Processing Center to retrieve the Probe telemetry for subsequent data processing and archiving, and distributes the raw scientific/calibration data to the scientists. Proper reception onboard

the Probe of the uplinked telecommands and their correct execution can be verified at this stage, based on analysis of the telemetry produced.

- Probe performance evaluation and possible failure-recovery analyses are performed, based on all available data (including previous checkouts), to evaluate the state of the Probe system and to prepare recovery actions for any anomalies that might have arisen.

Probe release

The Saturn orbit phase requires reaction times of the order of days, rather than the months of the cruise operations phase. Apart from two standard checkout periods, soon after the ring-plane crossing and before the Probe's release, some special tasks are performed.

Huygens has to rely on its onboard batteries for power after release. These are Li-SO₂ primary cells, which must be depassivated before use by applying a controlled load for a few minutes to each. This is a critical activity because of its non-reversibility, and must be performed as close as possible to Probe separation in order to minimise the impact on battery capacity. The operation's success, on the other hand, has to be verified while the Probe is still attached to the Orbiter and commandable from the operations centre. The last Probe checkout before release would be too early, so a special operations sequence is foreseen for this activity about 8 days before release. One day before release, the three redundant coast timers are loaded with the value calculated to ensure that the Probe is woken up at the correct time, about 24 min before it reaches Titan's atmosphere. Before release, the content of these timers is checked on the ground to ensure their correct operation.

Figure 5. Probe system hardware/software interfaces

CDMS: Probe Command and Data Management Subsystem

CDS: Orbiter Command and Data Subsystem

EXPs: Probe Instruments

POSW: Probe Onboard Software

PSE: Probe Support Equipment

RX: PSE Receiver

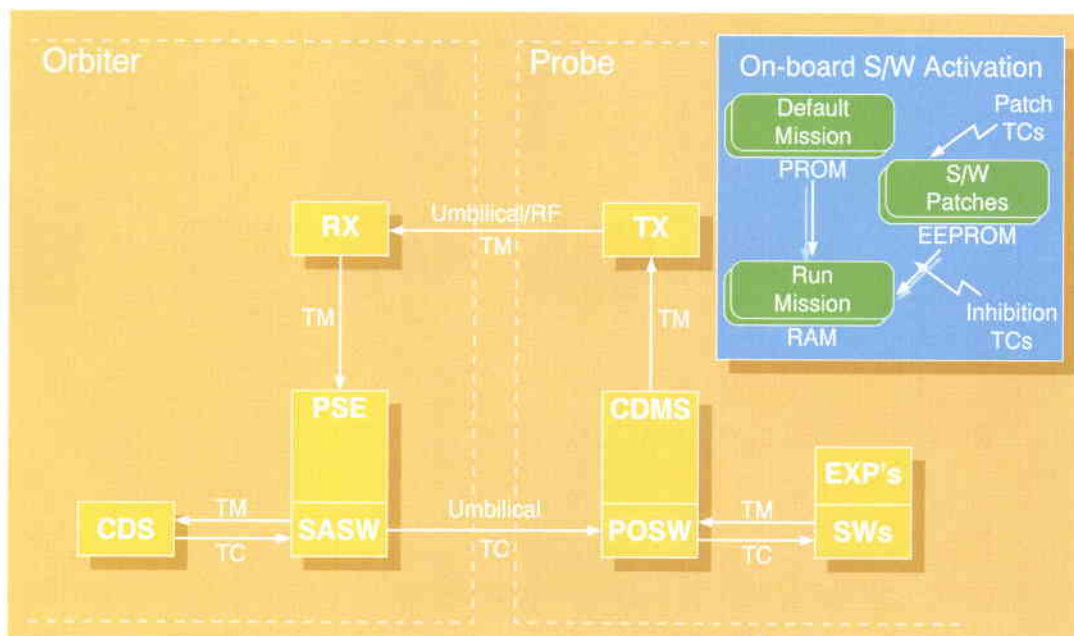
SASW: Support Avionics Software

SW: Instrument Software

TC: Telecommand

TM: Telemetry

TX: Probe Transmitter



A final 'go/no-go' decision to release the Probe is taken by ESOC, based on the successful verification of these final operations. In the event of a problem, the release can be aborted and postponed to the Orbiter's second Titan flyby. The coast phase starts at separation and ends at the entry into Titan's atmosphere at a nominal altitude of 1270 km; its maximum duration is 22 days.

Probe onboard software maintenance

The Huygens onboard software runs in a typical MIL-STD-1750A microprocessor environment and is configured in its operational form before launch. It is composed of two parts:

- Probe Onboard Software (POSW): its main purpose is to execute the Huygens mission according to a pre-defined timeline, to collect and format telemetry and, before Probe separation, to respond to telecommands. It resides within the Probe command and data management subsystem.
- Support Avionics Software (SASW): its main purpose is to provide a means of communication between the Orbiter and Probe. It resides within the Probe Support Equipment that remains attached to the Orbiter.

The onboard software has been designed to be reprogrammable. Indeed, in case of anomalies, software updates may be required as part of the contingency resolution. A software development facility is used for the maintenance of the Probe software and its validation at subsystem level. Its validation at system level is performed by means of the Probe simulator, which includes hardware emulators for the onboard processors. Once the validation process is satisfactorily

concluded, the software update is archived and prepared for uplinking to Huygens. The final step is its onboard verification by analysis of the appropriate telemetry. Instrument software maintenance is handled by the relevant Principal Investigator. ESOC, however, is responsible for verifying that these updates do not affect the Probe at system level and, once this point is cleared, for uplinking them to the Probe for delivery to the relevant instrument.

After launch, any modifications to the software code are made by software patching. This involves loading a patch into EEPROM by telecommand. This stored patch is accessed only at the next power-on of the processor, when it is applied to the main RAM. Figure 5 illustrates the process and the hardware/software relationships.

For the POSW and SASW, a new onboard memory image containing the patch is generated using the SDE, and passed to the HMCS Onboard Software Maintenance (OBSM) facility, where it is used to produce patch commands by comparison of the new image with a reference image of the onboard software. The HMCS provides utilities for the storage, management and configuration control of images, generation of patches and processing of memory dumps (including comparisons with stored images).

An equivalent process is used by the Principal Investigators when preparing software changes for their instruments, but the output is a set of instrument commands delivered to ESOC for incorporation into the next checkout sequence.

Titan and the Origin of Life on Earth*

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Introduction

The mystery of the origin of life on Earth will never be solved if our studies are confined to our own planet. Life originated sometime during the first billion years of Earth's history, perhaps more than once, from a subtle pre-biotic chemistry involving two key ingredients: carbon-based molecules and

potentially pre-biotic – chemistry is still at work. That is one of the reasons why we are so eager to explore Titan.

Why Titan?

Thanks to Voyager 1, we already know that Saturn's largest satellite has a predominantly nitrogen atmosphere containing a few percent of methane. Both of these compounds are being continuously broken apart by solar UV photons, precipitating electrons from Saturn's magnetosphere, and cosmic rays. The fragments of the parent molecules recombine to make new compounds, while the liberated hydrogen escapes into space (to become a species in Saturn's magnetosphere). Six simple hydrocarbons in addition to methane and five nitriles have been identified, as well as CO and a tiny trace of CO₂. Titan's visible atmosphere is filled with smog, which must be a mixture of simple condensates of the identified gases and polymers that have built up from molecules such as HCN and C₂H₂.

While this ubiquitous smog prevented Voyager from seeing Titan's surface, we do know that the average surface temperature is very low, at 94 K (-179° C). Water ice is almost certainly the main constituent of Titan's crust and upper mantle, but the vapour pressure of H₂O is so low at this temperature that this abundant

The relevance of Titan to the study of pre-biotic chemistry and the origin of life on Earth will be addressed by an interdisciplinary group of Cassini/Huygens scientists using the different, but synergistic, data sets obtained by NASA's Cassini Orbiter and ESA's Huygens Probe. Titan's special importance lies in the primitive, chemically-reducing nature of its atmosphere. Cassini/Huygens instruments will determine what compounds form in this environment, and the results will be compared with models for pre-biological chemical evolution on Earth.

liquid water. The life we know today probably began some time near the end of Earth's accretional bombardment by icy and rocky planetesimals about 4000 million years ago. The record of the conditions and processes from that time has been obliterated by erosion and plate tectonics. We do not even know what the composition of the atmosphere was while the early steps in chemical evolution were occurring. To discover how chemistry became pre-biotic chemistry and then biology, we must go to another world where a primitive environment has been preserved and a complex organic –

* Abstracted from the article 'The Relevance of Titan and Cassini/Huygens to Pre-biotic Chemistry and the Origin of Life on Earth' by T. Owen et al., in *Huygens: Science, Payload and Mission*, ESA SP-1177, August 1997. That volume also includes the paper 'Titan's Organic Chemistry and Exobiology' by F. Raulin.

Figure 1. To discover how chemistry on Earth became pre-biotic chemistry and then biology, we must go to another world where a primitive environment has been preserved and a complex organic chemistry is still at work

compound cannot supply the oxygen that is necessary to change the chemistry of Titan's atmosphere to an oxidising condition. A small amount of OH is supplied by ice grains from Saturn's rings and icy satellites and by impacting comets. This is adequate to convert some CH_4 to CO and some CO to CO_2 , but it is not sufficient to produce a CO_2/N_2 atmosphere, such as we find on Mars and Venus. CH_4 is still the most abundant form of carbon, just as it is in the atmospheres of the giant planets.

In other words, Titan provides us with an opportunity to travel back in time. Conditions on Titan today resemble the anoxic environment on Earth in which the chemical reactions necessary for the origin of life must have taken place. The fundamental difference from the early Earth is Titan's low temperature. As we discussed earlier, there is no chance of there being liquid water on Titan's surface, except from possible transient heating events such as vulcanism (if there is any) or from impacts by comets or meteorites – possibilities to be examined by Cassini/Huygens. The absence of liquid water prevents the origin of life as we know it on Earth. Instead, we must focus our investigations on the nature of the chemical reactions taking place spontaneously in Titan's atmosphere and on the surface, where the environment will again be different from that on Earth. It is very doubtful that much bedrock is exposed. However, if there are rocks, any liquid water or ammonia would act on them to produce clays or other active silicate surfaces that could serve as templates for complex organic polymers. While such activity is viewed as being very limited at best, it cannot be categorically ruled out on the basis of the evidence we have today.

Chemistry on Titan

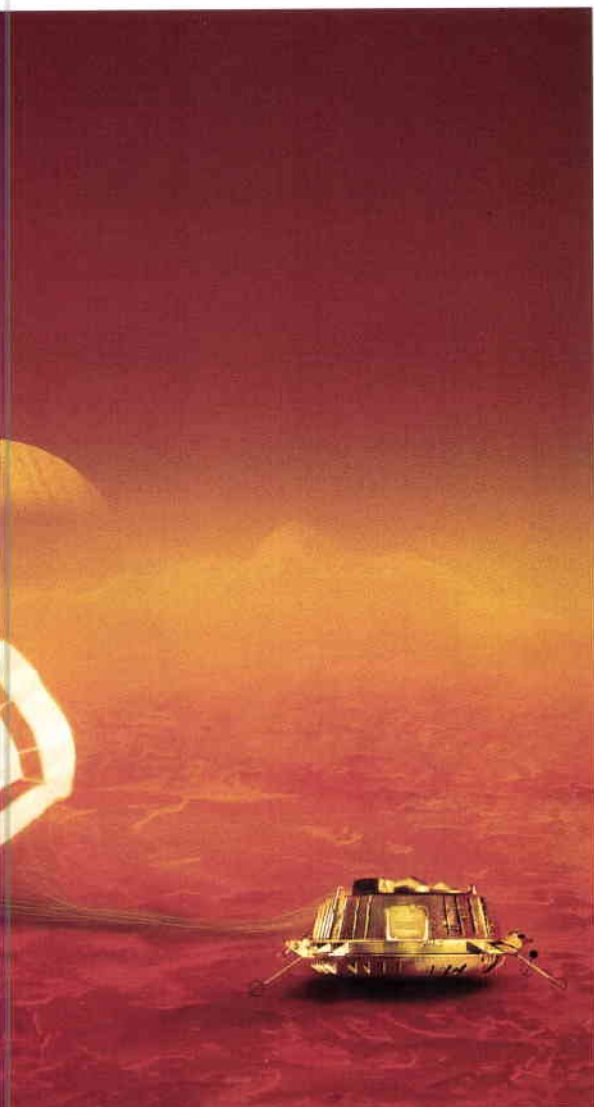
What compounds are likely to be produced under these conditions? Titan offers us a kind of controlled experiment to study pre-biotic chemistry on a planetary scale. Titan is a world where organic chemistry has been proceeding for 4500 million years; at low rates, obviously, because of the low temperature, but for very long times. There may even be pools of liquid hydrocarbons in which compounds produced in the atmosphere can be concentrated and further reactions can occur. We are eager to learn what compounds are produced, and what reaction pathways are taken as chemistry proceeds from the simple, abundant molecules towards more complex compounds.

We must confess that, despite the giant steps made by Voyager, our understanding of this system is still very limited. The best photo-



chemical models for Titan's atmosphere predict that ethane should be the main organic product of atmospheric reactions. If that were true, we would expect to find huge seas of ethane on Titan's surface, since the equivalent of a 1-3 km-deep global ocean of this compound should have been produced during the last 4500 million years. Yet radar and near-infrared observations from Earth have failed to find any evidence of hydrocarbon oceans. This is doubly vexing, since such oceans have also been invoked as reservoirs for Titan's atmospheric methane, 'which is constantly being destroyed, as has already been described.

Why is there any methane left today? How is it resupplied – by internal or external sources? Where is all the expected ethane? The fact that we have no answers to these simple, basic questions shows how far we are from understanding the chemistry of a primitive reducing atmosphere. Once we have thoroughly investigated the chemistry on Titan, we can expect to be in a much better position to deal with the far more complex issue of the origin(s) of life in the Solar System.



Several Cassini Orbiter instruments and most of those on Huygens will provide critical information on Titan's complex organic chemistry. In particular, they will provide new opportunities for the detection of organic compounds, including those not yet observed but already assumed to be present in Titan's atmosphere. Huygens will measure vertical concentration profiles of many of the constituents, in the gas and condensed phases, and vertical profiles of energy deposition in the atmosphere – data of prime importance for understanding the processes of formation and evolution of organic matter in Titan's environment. On the Orbiter, the radar and infrared spectrographic instruments will allow many of the results obtained from Huygens' descent at a single location to be extrapolated to a global scale and to be monitored for temporal variations over the span of the Orbiter's four-year orbital tour. These data will reveal the chemical and physical nature of Titan's unknown surface – information essential for understanding the full cycle of organic chemistry that has taken place on that world over 4500 million years.

Titan's primitive reducing atmosphere

As previously noted, we do not know what the composition of the Earth's early atmosphere was at the time life began. We know that free molecular oxygen was missing; the O_2 we have today is a gift of green-plant photosynthesis. The absence of O_2 is beneficial to the origin of life, since all our attempts to simulate the early steps in chemical evolution have taught us that this pre-biological chemistry cannot proceed in the presence of free oxygen. But what gases were present? Only CO_2 , CO and N_2 ? Or was there some CH_4 and NH_3 , constantly regenerated by impacts?

If the volatile elements we now find in Earth's atmosphere were originally delivered by comets, as some scientists believe, we might expect the elemental composition of Titan's atmosphere to be similar to the atmosphere of the early Earth. Titan is made of 'cometary' material. It must have accumulated from ice-rich planetesimals that formed in the Saturn subnebula, augmented by real comets bombarding the satellite from outside the Saturn system. Depending on the extent of the influence of Saturn subnebula chemistry on Titan's early atmosphere, the initial atmospheric compositions on both Earth and Titan may have been very similar indeed.

In any case, Titan will serve as a full-scale 'end member' environment in studies of possible atmospheres for the early Earth. It is a world in which all the volatiles were delivered by ice-rich planetesimals and comets. It provides a reference planetary environment for studying the role of liquid water in chemical evolution since organic chemistry on Titan has been occurring for 4500 million years in the absence of this universal solvent. An important task will be to reconstruct Titan's original atmosphere from the clues provided by the present abundances and isotopic ratios of atmospheric volatiles as measured by Cassini/Huygens. This reconstructed atmosphere will then constitute the initial environment from which the organic compounds analysed by the Probe were produced.





The Cassini Mission to Saturn and Titan

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Introduction

The Cassini/Huygens mission is an international venture between NASA, ESA, the Italian Space Agency (ASI) and several separate European academic and industrial partners. The mission is managed for NASA by the Jet Propulsion Laboratory (JPL) in Pasadena, California. After an interplanetary voyage of 6.7 years, the spacecraft will arrive at Saturn on 1 July 2004, where it will brake into orbit around the planet. ESA's 318 kg Huygens Probe will execute its mission in November 2004, at the end of the first of Cassini's many orbits about Saturn. Having relayed the Huygens data, the Orbiter will then continue its intensive exploration of the system through June 2008.

When Cassini/Huygens was launched from Cape Canaveral on 15 October 1997, the 5.5 t, 6.8 m-high spacecraft carried a suite of scientific sensors to support 27 investigations probing the mysteries of Saturn's system. In addition to a fascinating atmosphere and interior, the vast system contains the most spectacular of the four planetary ring systems, numerous icy satellites with a variety of unique surface features, a huge magnetosphere teeming with particles interacting with the rings and moons, and the intriguing moon Titan – slightly larger than the planet Mercury and with a hazy atmosphere denser than Earth's.

Cassini/Huygens was launched atop a Titan-4B/Centaur from Launch Complex 40 at the US Air Force Cape Canaveral Air Station in Florida. Though under the primary control of the USAF 45th Space Wing, launch operations also involved the efforts of many other agencies, technical centres and contractors. Once injected into space and acquired by the Deep Space Network (DSN) tracking antennas, mission control shifted to the Mission and Science Operations (MSO) teams at JPL, with Probe support from ESA's European Space Operations Centre (ESOC) in Darmstadt, Germany (see the article by Sollazzo et al. in this issue).

On reaching Saturn in mid-2004, Cassini will swing to within 20 000 km of the cloud tops (an altitude only 1/6th the diameter of Saturn) to

begin the first of 74 planned orbits. In late 2004, Cassini will release the Huygens Probe for a descent of up to 2.5 h through Titan's dense atmosphere. The instrument-laden Probe will beam its findings to the Orbiter for storage and then relay to Earth. The Huygens portion of the mission is covered in detail in the Lebreton & Matson and Hassan & Jones articles in this issue.

What we know about Titan is certainly tantalising. Its brownish-orange, hazy atmosphere of nitrogen, methane and complex array of carbon-based molecules hides a frigid surface that may contain subsurface reservoirs or perhaps even lakes of liquid ethane and methane. Much of Titan's interior and surface is probably frozen water ice, with perhaps thin patches of overlying frozen methane and ammonia. As high-energy particles and ultraviolet radiation bombard the nitrogen and methane molecules in the atmosphere, these and further reactions create a variety of organic molecules that clump together and rain slowly down. Whether this material collects on the surface or sinks into surface pores is not known. In many ways, Titan's environment may resemble the chemical factory of primordial Earth. Though the extreme cold makes the possibility of life unlikely, Titan may still provide valuable clues to the chemistry of early Earth.

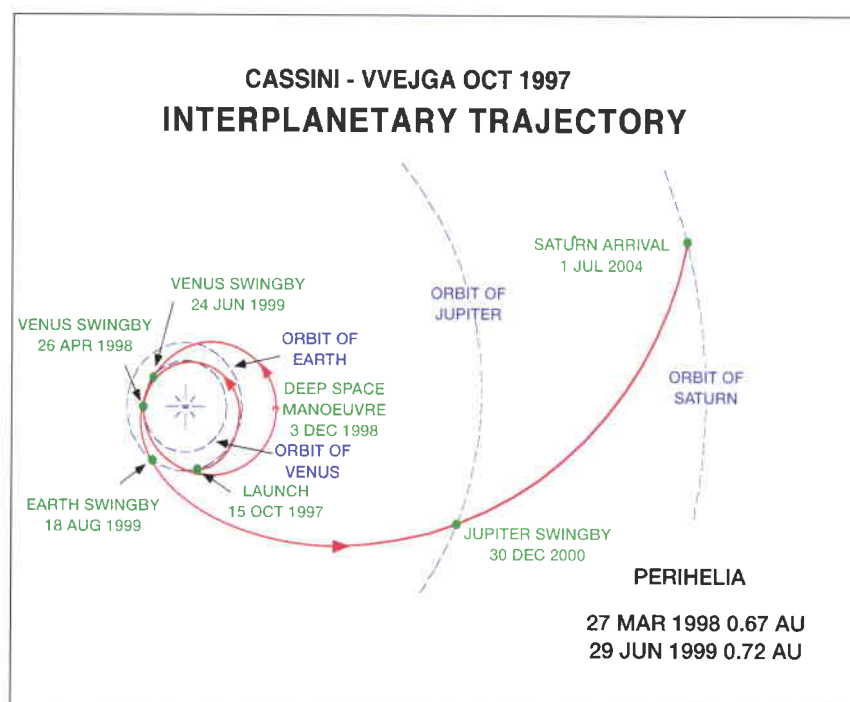
The Orbiter will execute 50 close flybys of the moons, including more than 40 of Titan. In addition, there will be more than 25 distant flybys of the icy moons. Cassini's orbits will also allow it to study Saturn's polar and equatorial regions.

Throughout the mission, costs will be contained and efficiency enhanced by streamlined operations. The Cassini Project uses simplified organisational groups to make decisions. Flight controllers will take advantage of high-level building blocks of spacecraft action sequences to carry out mission activities. New technology includes powerful new computer chips, solid-state recorders,

gyroscopes with no moving parts, and solid-state power switches.

Mission design

Delivering Cassini and its large complement of scientific instruments to Saturn and Titan produced a spacecraft launch mass of 5548 kg, more than half of which is propellant for trajectory changes. Not even the powerful Titan-4B/Centaur can reach Saturn directly with this payload, but it can provide sufficient energy for a direct trajectory to Venus. Here, the great velocity gains from a gravity assist must be used to reach Saturn 6.7 years after launch, by flying by Venus twice and Earth and Jupiter once each – the so-called 'VEJGA trajectory' (Venus-Venus-Earth-Jupiter Gravity Assist).



Cassini requires several planetary swingbys to gain sufficient Sun-relative speed to reach Saturn almost 7 years after launch (Courtesy of JPL)

As the Jupiter-Saturn connection is only available for one 3-year period every 20 years (Voyager used the 1976-1978 equivalent), it turns out that departures later than Cassini's primary launch period (6 October - 4 November 1997, with contingency days available through 15 November) lose the energy gain available from Jupiter and must endure much longer flight times if they are to make it to Saturn with sufficient performance to attempt a minimum tour mission. For the VVEJGA route, the Sun-relative speed gains for each of the four swingbys are roughly 6, 7, 6 and 2 km/s, respectively. For the secondary launch period from 28 November 1997 to 11 January 1998, the speed gains from the VEEGA route are about 6 km/s for each of the three swingbys, with arrival at Saturn some 2.3 years later than the preferred arrival date of 1 July 2004, for the primary mission.

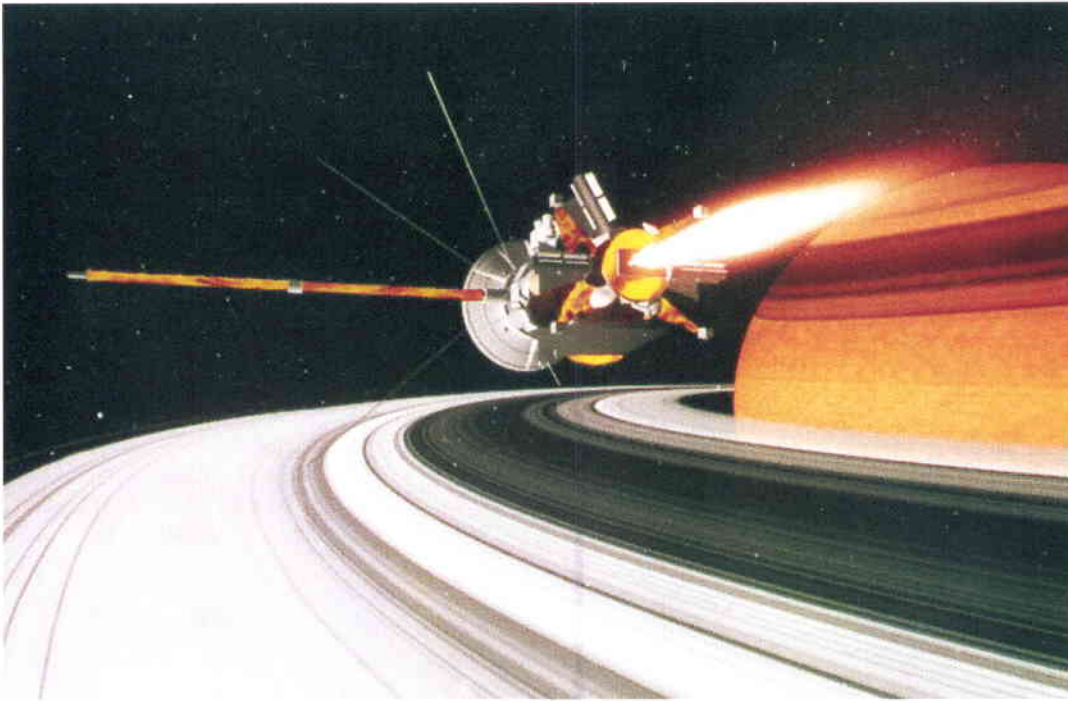
The primary arrival date is favourable from three points of view. It allows a close flyby (52 000 km) of the moon Phoebe (likely a captured asteroid in a distant, retrograde orbit) some 19 days before Saturn Orbit Insertion (SOI). The tilt of Saturn's rings is more favourable for imaging and radio-science observations than it is for later arrivals. Finally, the spacecraft power available during the tour from the Radioisotope Thermal Generators (RTGs) is higher than it would be after the longer journey times of the later launches.

Daily launch windows from Cape Canaveral opened at 09:38 UT on 6 October and lasted for up to 140 min each launch day, moving earlier by about 6 min daily. During the cruise to Saturn, activities are limited primarily to engineering and science instrument maintenance and calibrations, navigation data collection, trajectory corrections and gravitational-wave searches during 40-day periods around solar oppositions beginning in December 2001.

The probability of accidental entry during the >1000 km altitude Earth swingby will be controlled to 10^{-6} through measures such as trajectory aim-point biasing, precision navigation, robust spacecraft design against propulsion- and micrometeoroid-induced failures, and rigorous flight-team training. Scientific observations will be made of the Saturnian system during the late cruise phase as Cassini approaches. Present funding and project planning do not allow for scientific data to be collected during the earlier planetary swingbys.

On arrival at Saturn, Cassini will make its closest approach to the planet, passing only 20 000 km above the cloud tops. It will fire one of its two redundant engines on 1 July 2004 for 96 min to slow its speed by 622 m/s for SOI; braking into a 1.33×178 Saturn radii (R_s), 148-day, 16.8° orbit will consume 830 kg of the main propellant supply. A 50-min, 335 m/s burn 13 days after apoapsis of the post-SOI orbit will raise periapsis to $8.2 R_s$ to target Cassini for a Titan encounter and Huygens' entry on 27 November 2004. If any problem with the spacecraft or ground system prevents execution of the Probe mission on the first Titan pass, a decision can be made as late as a few days before Probe separation to delay until the second Titan encounter on 14 January 2005.

On 6 November 2004, 22 days before the first Titan flyby, the entire spacecraft will be manoeuvred into an impact trajectory with Titan. Two days later, the Orbiter will turn to orient the Probe to its entry attitude, spin it up to just over 7 rpm, and release it with a



Cassini begins the Saturn Orbit Insertion (SOI) burn on 1 July 2004 (Courtesy of David Seal/JPL)]

separation velocity of about 0.3 m/s. Two days after separation, the Orbiter Deflection Manoeuvre (ODM) of 45 m/s ensures that it will not follow the Probe into Titan's atmosphere (by aiming 1200 km off Titan's limb) and establishes the proper geometry (by slowing down) for the Probe Relay Link. Huygens is targeted for an entry angle of -64° and a dayside landing 18.4°N of Titan's equator and some 200°E of the sub-Saturn point.

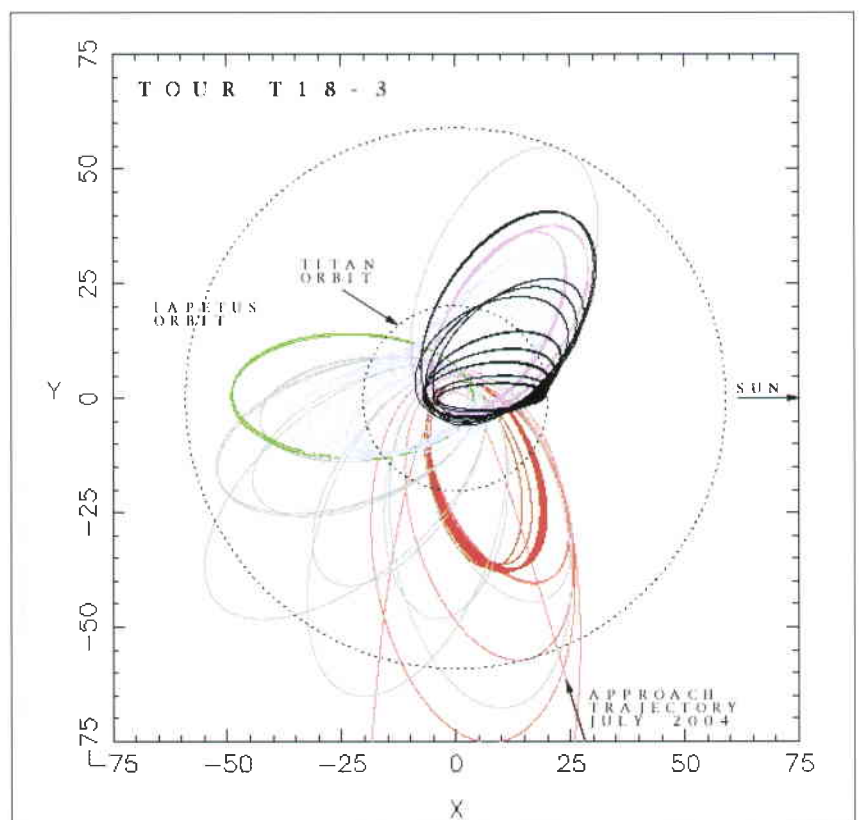
After Huygens enters Titan's atmosphere at 6 km/s, decelerates to 400 m/s in less than 3 min, and deploys its series of parachutes, it will transmit its findings to the Orbiter for up to 2.5 h during descent, and possibly for another 30 min from the surface. The Orbiter will receive these data over its High-Gain Antenna (HGA) for redundant storage in its two Solid-State Recorders (SSRs), then turn later to play back these precious data to the waiting radio telescopes on Earth.

Cassini's tour phase begins after completion of Huygens' mission and ends four years after SOI. The baseline tour consists of 74 orbits of Saturn with various orientations, orbital periods ranging from 7 to 155 days, and Saturn-centred periapses ranging over about 2.6 - 15.8 R_s . Orbital inclinations with respect to Saturn's equator range from 0° to 75° , providing opportunities for ring imaging, magnetospheric coverage and assorted Earth, Sun and stellar occultations by Saturn, Titan and the ring system. Most of the 43 Titan encounters have flyby altitudes of 950 - 2500 km. As a result of Titan's considerable mass, the Saturn-relative total gravity swingby gains amount to about 33 km/s (more than that

gained during the interplanetary journey), easily enough to move the Saturn-relative orbits through a wide range of desired observational geometries. The baseline tour also contains seven close flybys within 1000 km of icy satellites, and 27 additional distant flybys of icy satellites within 100 000 km.

The tour designers have developed an elaborate sequence of Titan swingbys to achieve the many scientific remote-sensing and in-situ data-collection conditions requested by

After delivering the Huygens Probe, the Orbiter will make 43 close gravity-assisted swingbys of Titan to achieve a variety of Saturn geometries for its 12 instruments (Courtesy of JPL)



the scientists. It is crucial that the navigation accuracy for each swingby be very precise, because the total delta-V available for flying the entire 4-year tour is only 500 m/s, i.e. less than the average delta-V assist (770 m/s) from each Titan swingby. By using radiometric tracking data and optical navigation images of Titan and other satellites against a star background taken on each orbit, the Navigation Team predicts control errors at the 10 km level for the Titan swingbys, sufficient for the available propellant.

The mission designers are developing an integrated plan to allow the flight and ground systems to collect and return the desired science data, while Cassini remains 'on the tour'. Sequences of operational routines are used rather like building blocks to execute the necessary engineering support and scientific activities. These various 'operational modes', 'data modes' and 'templates' can be strung together to ensure that spacecraft subsystem and instrument capabilities are used to best advantage. As the three RTGs do not provide sufficient power to turn all the instruments on simultaneously, the various instruments must be operated in logically related subsets. Hence, such operational modes as 'Optical Remote Sensing', 'Radar/INMS' (Ion and Neutral Mass Spectrometer) and 'Downlink Fields/ Particles/ Waves' convey their intent.

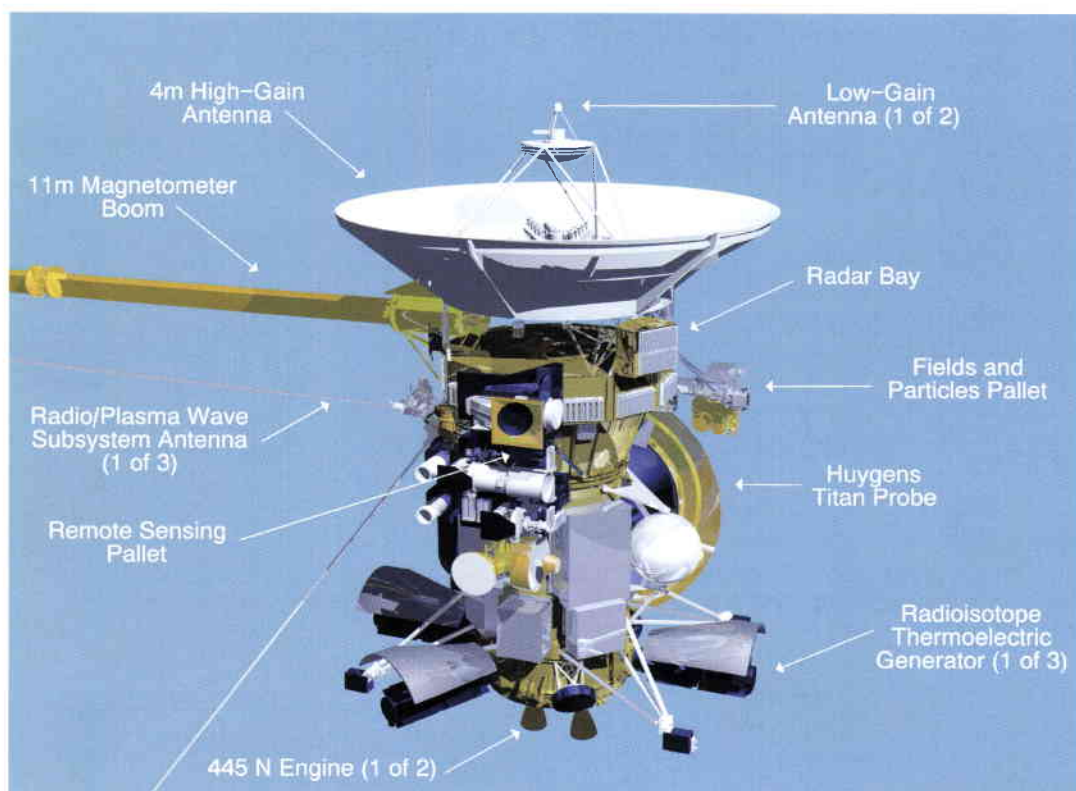
The majority of the scientific instruments are body-mounted, making it is necessary to turn the entire spacecraft, point in different directions to perform the desired measure-

ments, record these data on the two SSRs (which can hold 1.8 Gbit each), and finally turn to Earth to radio these data to the ground. During each orbit about Saturn, there are 4 to 7 days of 'high activity', with the remainder spent in 'low activity'. The former generally occurs near Saturn and the satellite flybys, with intensive data-collection periods lasting about 16 h daily, followed by 8 h of playback to either a 70 m antenna or a 34/70 m array, capturing up to 4 Gbit daily (by interleaving real-time and SSR data during each playback). During low activity, the Orbiter may simply roll to collect fields and particles data to broadcast to a smaller 34 m antenna each day, though off-Earth turns are still allowed as long as downlink data return levels do not exceed about 1 Gbit daily.

The Cassini Orbiter

The Cassini Orbiter is one of the largest and most complex robotic spacecraft ever built. Together with the Huygens Probe, it is twice the size of Galileo: 6.8 m tall and 4 m across. Carrying over half its mass in propellant (3132 kg), the total spacecraft with its instruments and Huygens weighs 5548 kg.

The Orbiter's main body is formed by a stack consisting of the lower equipment module, the propulsion module, the upper equipment module, and the High-Gain Antenna (HGA). Attached to this stack are the Remote-Sensing Pallet, the Fields and Particles Pallet, and the Huygens Probe. Some instruments, such as the Titan Radar and the Radio and Plasma



Principal features of the Cassini/Huygens spacecraft (Courtesy of JPL)

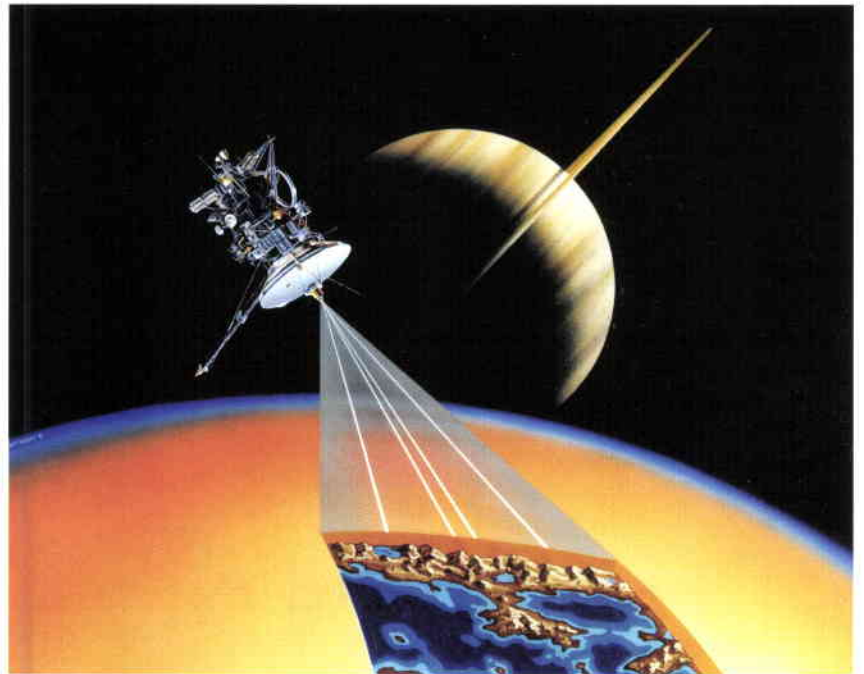
Wave Subsystem (RPWS), are attached to the upper equipment module. The two equipment modules are also used for externally mounting the magnetometer boom and the three power-providing RTGs. The spacecraft electronics bus is part of the upper equipment module, supporting data handling (including the command and data subsystem and the radio-frequency subsystem), instruments and other spacecraft functions. During the inner Solar System cruise and science tour, the 4 m-diameter HGA communicates with the Deep Space Network at a maximum of 166 kbit/s, using its X-band transmitter and only 20 W power (19 W at end of mission). Two Low-Gain Antennas (LGAs) transmit data and receive commands when the HGA cannot be pointed at Earth.

Once on its way to Saturn, the Orbiter uses two 445 N main engines and 16 smaller 0.5 N thrusters clustered in groups of four in redundant pairs for propulsion and manoeuvres. The primary and backup main engines have separate feed systems. A gimbal mechanism directs thrust through Cassini's centre of gravity and can swivel $\pm 12.5^\circ$ in two orthogonal axes. The main engines use the helium-pressurised hypergolic combination of monomethyl hydrazine ($\text{N}_2\text{H}_3\text{CH}_3$) fuel and nitrogen tetroxide (N_2O_4) oxidiser. A separate 132 kg tank of hydrazine (N_2H_4) is used for the thrusters. In general, the main engines are used for all manoeuvres requiring a delta-V greater than 0.8 m/s. The thrusters can provide as little as 0.015 N/s for attitude control.

Mounted below the main engines is a retractable cover that protects them from micrometeoroids during cruise. The thin disilicide refractory ceramic coating on the inside of the engines is especially vulnerable to micrometeoroid damage: it could lead to burn-through and engine loss. The main engine cover can be extended and retracted many times and has a pyrotechnic ejection mechanism should there be a mechanical problem that interferes with main-engine operation. During cruise, the cover remains closed when the main engines are not in use.

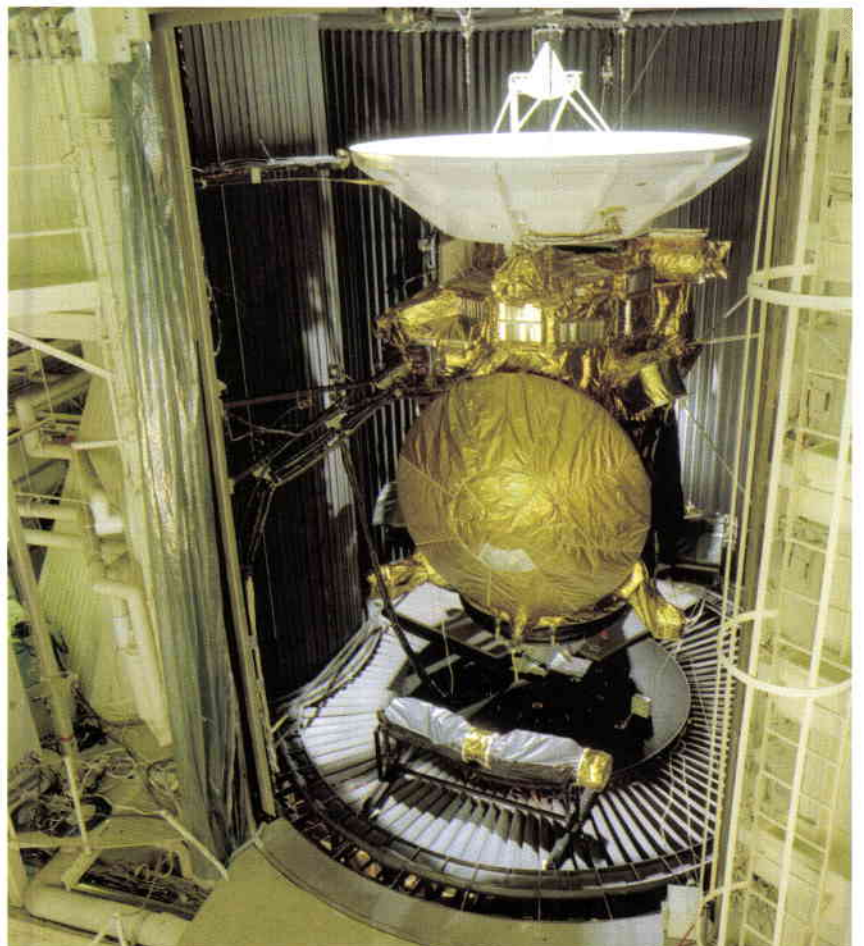
Power is supplied to the spacecraft by three RTGs, providing about 700 W. Solar electric power generation is impractical so far from the Sun, as the enormous size of an effective solar array would be too massive and bulky to fit on any launch vehicle.

The Command and Data Subsystem (CDS) receives ground commands via the Radio Frequency Subsystem (RFS). The CDS then distributes the commands designated for other

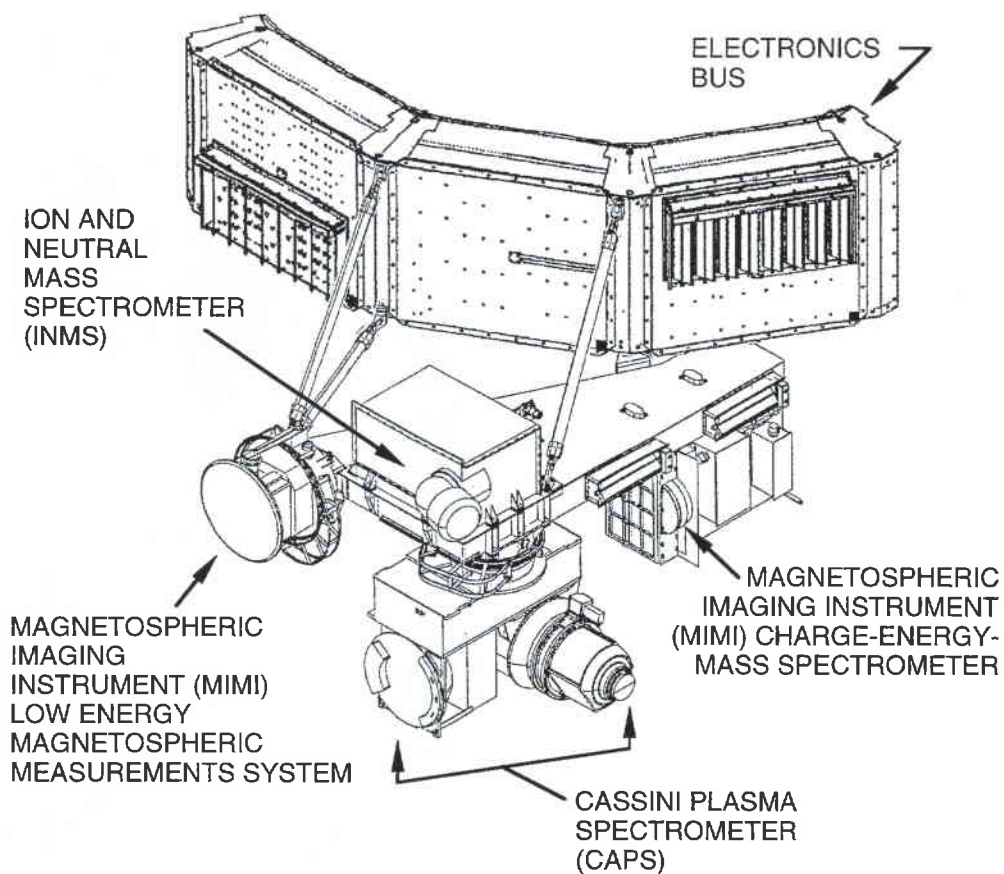
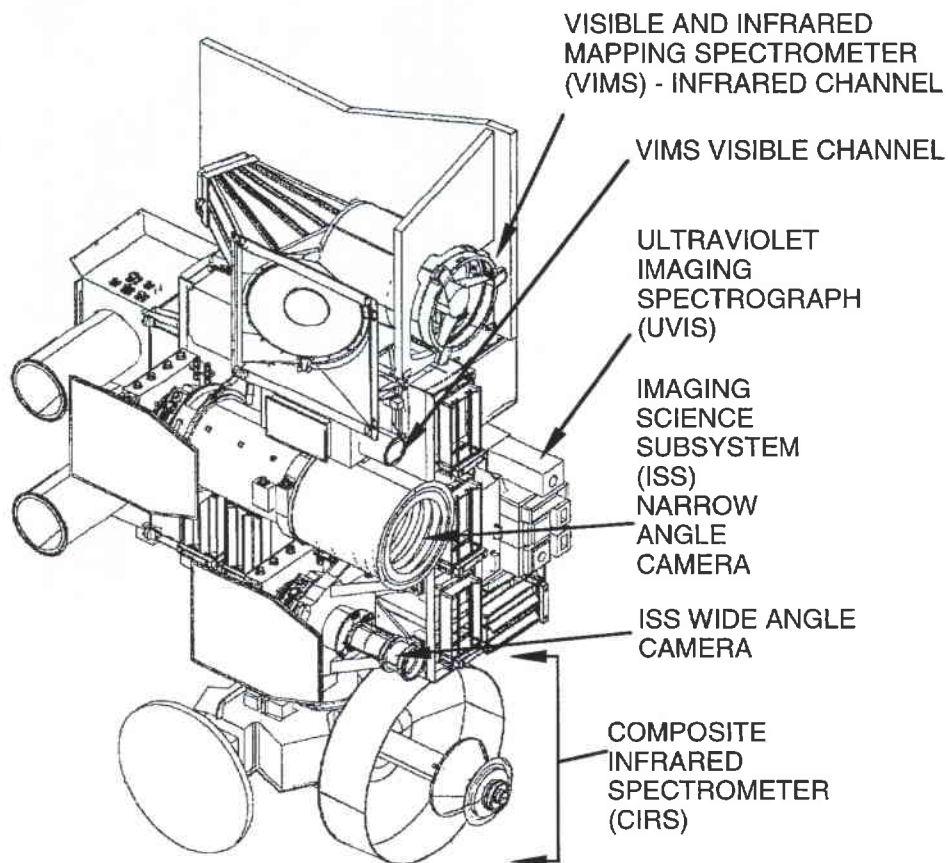


Cassini's High-Gain Antenna (HGA) is able to operate at S-, X-, Ka- and Ku-band. In addition to communications (X-band with Earth and S-band with Huygens), radio-science measurements will probe Saturn and satellite gravity fields, rings, atmospheres and surfaces. This artist's concept illustrates the radar mapping of Titan's shrouded surface of Titan at Ku-band. Radar images will be taken at a typical resolution of 500 m. Altimetry and passive radiometry measurements will also be made. Approximately 1% of Titan's surface can be mapped during a flyby. Full coverage will be accomplished by combining the high-resolution radar mapping with lower-resolution passive radiometry (Courtesy of JPL)

The Cassini Orbiter and Huygens Probe in the solar thermal vacuum test chamber (Courtesy of JPL)



The locations of the imaging
science instruments on the
Remote Sensing
Pallet (Courtesy of JPL)



The locations of some of
the fields and particles
experiments on the
Fields and Particles
Pallet (Courtesy of JPL)

subsystems or instruments, executes those commands that are decoded as CDS commands, and stores sequence commands for later execution. There are two CDSs so that the mission can continue should one fail.

Cassini carries two identical 1.8 Gbit SSRs, each capable of transferring data at more than 470 kbit/s. Each CDS is linked to the SSRs such that each can communicate (read/write) with one SSR, but not both simultaneously. The CDS receives data destined for the ground on the data bus from other subsystems, processes it, formats it for telemetry and delivers it to RFS for transmission to Earth.

CDS software contains algorithms that provide protection for the spacecraft and the mission in the event of a fault. In the case of a serious fault, the spacecraft will be placed in a safe, stable, commandable state (without ground intervention) for at least two weeks to give the operations team time to solve the problem and send the spacecraft a new command sequence. It also automatically responds to a pre-defined set of faults (problems) needing immediate action.

The X-band RFS provides the telecommunications facilities for the spacecraft and is used as part of the radio-science instrument. The Ultra Stable Oscillator (USO), the Deep Space Transponder (DST), the X-band Travelling Wave Tube Amplifier (TWTA), and the X-band Diplexer are also used as part of the radio-science instrument.

The Attitude and Articulation Control Subsystem (AACS) provides dynamic control of Cassini's orientation. It keeps the spacecraft orientation fixed for HGA and remote-sensing pointing and performs target-relative pointing as well as repetitive motion required during imaging such as scans and mosaics. Spacecraft rotation during the Saturn tour that requires high pointing stability is normally controlled by the three main Reaction Wheel Assemblies (RWAs), although modes requiring faster rates or accelerations may use the thrusters. The AACS is capable of supporting a pointing accuracy of 1 mrad with a stability of 8 μ rad/s, and rotation rates of 0.02 - 1°/s. The AACS also controls the main-engine gimbals.

The AACS uses Inertial Reference Units (IRUs) for angular-motion measurements about three orthogonal axes. Two of the three are operational at any one time, with one providing backup in case of equipment failure. Together with the Stellar Reference Unit (SRU) star tracker, the IRUs form the basis of Cassini's attitude-determination system.

The heart of each IRU is a set of four solid-state hemispherical resonator gyroscopes (HRGs) developed by the Delco Division of Hughes Aircraft Co. The inertially sensitive element in each HRG is a fused-silica shell, the hemispherical resonator. If a standing wave is established on the shell (much like making a wine glass 'sing' by sliding your finger around the rim) and the shell is rotated about its axis, the oscillating mass elements experience forces that cause the standing wave to precess with respect to the shell. The precession angle is a constant fraction of the angle through which the shell has rotated, allow precise measurement of angular motion in the axis of the HRG.

Each IRU weighs less than 8 kg. The units are designed to meet all performance requirements over 2500 h of testing and 30 000 h of in-flight operation. They must also meet requirements over 200 on/off cycles in testing and 500 on/off cycles in flight.

The SRU is a 15 deg-square field of view star tracker that provides three-axis attitude measurements. The redundant SRU can provide the AACS flight computer (AFC) with up to 50 000 pixels of information per second. AFC software algorithms can establish and maintain stellar reference by comparing incoming pixel frames to an onboard catalogue of some 5000 stars. Three to five stars are commonly tracked at any one time.

Cassini uses a digital Sun Sensor Assembly (SSA) to detect the Sun when it is in the sensor field of view. Following detection, the measured Sun location determines the spacecraft attitude to sufficient accuracy to facilitate star identification by the SRU. The SSA also provides Sun reference for spacecraft thermal 'safing' (i.e. shutdown in case of thermal overload). The SSA has 2-for-1 redundancy, and at least one SSA will be powered on at all times during the mission.

Thermal control is accomplished by several means, the most visible being the black-and-gold Multi-Layer Insulation (MLI). In addition to the automatically positioned reflective louvers covering the 12-bay electronics bus, strategically-placed heaters and radiators also help to provide thermal control for systems and instruments as Cassini travels between 0.61 and 10.1 AU from the Sun. The thermal-control elements must dissipate the waste heat from the RTGs, as well as the 700 W consumed by the various electronics subsystems. The majority of the electronics must be maintained within 5-50°C. In the case of VIMS and CIRS, where substantial thermal isolation from the

platform and spacecraft is required, temperature control is provided as an integral part of the instruments themselves. The thruster clusters are temperature-controlled with Variable Radioisotope Heater Units (VRHUs) and catalyst bed electrical heaters. Electrical heaters are also used on the main engines. A heat shield protects the rest of the engine from radiant heating during and after main-engine firings.

Cassini's instruments are capable of observing from the infrared to the ultraviolet, as well as detecting charged particles, dust and magnetic fields. Its radar will pierce the clouds surrounding Titan to provide detailed images and measurements of its surface. During the four-year orbital tour of Saturn, hundreds of thousands of images in many frequencies will be sent back. The science instruments and their purposes are listed in Table 1.

Table 1. Cassini Orbiter instruments

Instruments	Participating Countries	Measurements	Techniques
<i>Optical remote-sensing instruments</i>			
Composite Infrared Spectrometer (CIRS) V. Kunde, NASA/GSFC (USA)	USA, A, F, G, I, UK	High resolution IR spectra, 10-1400 cm ⁻¹	Spectroscopy using 3 interferometric spectrometers
Imaging Science Subsystem (ISS) C. Porco, Univ. of Arizona, Tucson, USA	USA, F, G, UK	Photometric images through filters, 0.2-1.1 µm.	Imaging with CCD detectors; 1 wide angle camera (61.2 mrad/fov); 1 narrow angle camera (6.1 mrad/fov)
Ultraviolet Imaging Spectrograph (UVIS) L. Esposito, Univ. of Colorado, Boulder, USA	USA, F, G	Spectral images, 55-190 nm, occultation photometry, 2 ms; H and D spectroscopy, 0.0004 nm resolution	Imaging spectroscopy, 2 spectrometers Hydrogen-Deuterium absorption cell
Visible and Infrared Mapping Spectrometer (VIMS), R. Brown, Univ. of Arizona, Tucson, USA	USA, F, G, I	Spectral images, 0.35-1.05 µm (0.073 µm res.), 0.85-5.1 µm (0.166 µm res.); occultation photometry	Imaging spectroscopy, 2 spectrometers
<i>Radio remote-sensing instruments</i>			
RADAR	USA, F, I, UK	Ku-band RADAR images 13,777.5 MHz; Radiometry, <0.5K resolution	Synthetic aperture radar; radiometry with a microwave receiver
Radio Science Subsystem (RSS) A. Kliore, JPL, Pasadena, USA	USA, I	Ka, S, and X bands; frequency, phase, timing, and amplitude	X- and Ka-band transmissions to Cassini; Ka-, S- and X-band transmissions to the Earth
<i>Particle remote-sensing and in situ measurement instrument</i>			
Magnetospheric Imaging Instrument (MIMI) S. T. Krimigis, JHU, Baltimore, USA	USA, F, G	Image energetic neutrals and ions <10 keV - 8 MeV/nucleon; composition. 10-265 keV/e ions; charge state; composition; directional flux. 20 keV-130 MeV ions; 15keV to >11 MeV electrons; directional flux	Particle detection and imaging. Ion-neutral camera (time of flight, total energy detector) Charge-energy-mass spectrometer Solid state detectors with 1) magnetic focusing telescope, and 2) aperture controlled ~45° field of view
<i>In situ measurement instruments</i>			
Cassini Plasma Spectrometer (CAPS), D. T. Young, SWRI, San Antonio, USA	USA, SF, F, H, N, UK	Particle energy/charge: 0.7-30,000 eV/e 1-50,000 eV/e 1-50,000 eV/e	Particle detection and spectroscopy. Electron spectrometer; ion mass spectrometer; ion beam spectrometer
Cosmic Dust Analyzer (CDA), E. Gruen, MPI, Heidelberg, D	G, CZ, F, N, UK, USA, ESA	Directional flux and mass of dust particles in range of 10 ⁻¹⁶ -10 ⁻⁶ g	Impact induced currents
Dual Technique Magnetometer (MAG), D. Southwood, IC, London, UK	UK, G, I, USA	B DC to 4 Hz up to 256 nT. Scalar field DC to 20 Hz up to 44 000 nT	Magnetic field measurement. Flux gate magnetometer; Vector/scalar magnetometer
Ion and Neutral Mass Spectrometer (INMS), J.H. Waite, SWRI, San Antonio, USA	USA, G	Fluxes of +ions and neutrals in mass range of 1-66 amu	Mass spectrometry
Radio and Plasma Wave Science (RPWS), D. Gurnett, Univ. of Iowa, Iowa, USA	USA, A, F, S, UK, ESA	E 10 Hz - 2 MHz B 1 Hz - 20 kHz Plasma density	Radio frequency receivers. 3 electric dipole antennas; 3 magnetic search coils; Langmuir probe current

Jean Dominique Cassini with the Paris Observatory in the background (Painting by Duragel, courtesy of the Observatoire de Paris)

Cassini and Huygens the Scientists

Jean Dominique Cassini was born in Perinaldo, Italy on 8 June 1625, and given the name Gian Domenico Cassini; he changed his name in 1673 on becoming a French citizen. Christiaan Huygens was born to a prominent Dutch family in The Hague, The Netherlands on 14 April 1628. His family was deeply involved in the sciences, literature and music.

Cassini became the head of the Paris Observatory in 1668, and spent much of his time observing Saturn, its moons and rings. He was an excellent and assiduous observer, discovering the moons Iapetus, Rhea, Tethys and Dione between 1671 and 1684, as well as the large gap (1675) between the A and B rings now known as the Cassini Division. He also measured the rotation rate of Mars, determined the orbits of Jupiter's satellites, and created a complete and accurate map of the Moon.

Cassini had great skills as an organiser and in making science exciting to the public; he was also a first-class courtier in a patronage economy that valued novelty. In Bologna, he transformed a cathedral into an observatory,



and in Paris he moved the Marly water tower to the Paris Observatory grounds for supporting very long telescopes. He personally supervised and participated in measuring the latitude and longitude of most French towns and villages. Though resistant to some new scientific ideas of his time, he and his sons and grandsons were a major presence at the Paris Observatory for almost 120 years.

Huygens, in addition to his cultural pursuits, also studied law and mathematics, and conducted experiments in mechanics and optics. Though his health was delicate, he was an accomplished dancer. Huygens discovered Saturn's large moon Titan in 1655, and was also the first to deduce (in 1656, but not reported until 1659) that Saturn was surrounded by a ring. He invented the pendulum clock, the first accurate time-keeping device, and was chosen as 'primus inter pares' ('first among equals') to organise the Academie Royale des Sciences in Paris when it was founded in 1666. Young scientists were often attracted by his brilliance, but Huygens preferred solitary contemplation to team efforts. His contributions to mathematics, astronomy, time measurement and the theory of light are considered to be of fundamental importance.

Christiaan Huygens (1629 –1695) by Vaillant (Courtesy of Huygens museum Hofwyck, Voorburg, The Netherlands)

Saturn

Although Saturn has been known since pre-historic times, its ring system was not discovered until the 17th Century, and much of what is now known came out of the Voyager flybys of 1980-81. Although its equatorial diameter is about 80% that of Jupiter, it has less than one third the mass, making it the only planet less dense than water (70%). Saturn's interior is suspected to be similar to Jupiter's, with a small rocky core, a liquid metallic hydrogen layer and a molecular hydrogen layer.

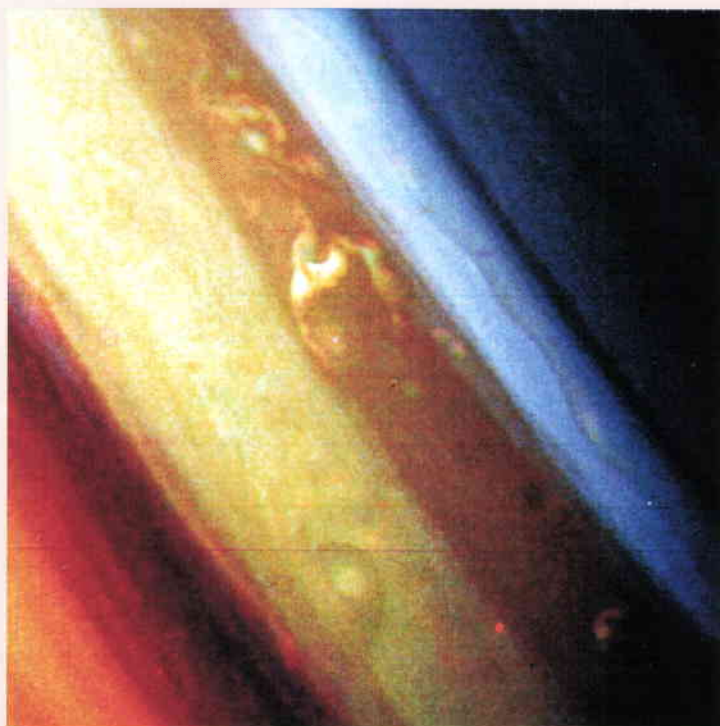
Saturn's hazy yellow hue is marked by broad atmospheric banding similar to, but less well defined than, that found on Jupiter. The atmosphere is primarily composed of hydrogen with a small amount of helium and traces of other gases (e.g. methane and ammonia). Near the equator, upper-atmosphere winds can reach 500 m/s, blowing mostly eastwards, but they appear to slow at higher latitudes. At latitudes beyond $\pm 35^\circ$, these winds can alternate east and west with increasing latitude.

Despite receiving only 1% or so of the sunlight that reaches the Earth, Saturn maintains a relatively high temperature. In fact, it radiates more heat than it receives. Some can be explained by Saturn's immense gravity compressing its interior (the Kelvin-Helmholtz mechanism), and by the condensation and 'raining out' of helium, which generates heat as the drops of liquid helium lose accumulated kinetic energy through friction with lower layers.

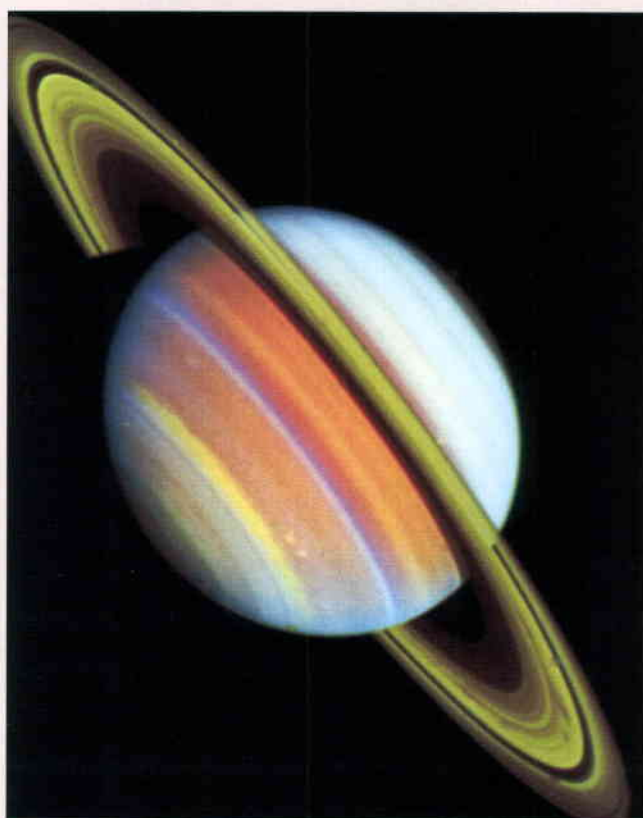
Saturn Facts

Mass (kg)	5.69×10^{26}
Equatorial diameter (km)	120 660
Mean density (kg/m^3)	690
Escape velocity (m/s)	35 600
Average distance from Sun (AU)	9.539
Rotation period (length of day in Earth hours)	10.6
Revolution period (length of year in Earth years)	29.46
Obliquity (tilt of axis in degrees)	26.7
Orbit inclination (degrees)	2.49
Orbit eccentricity (deviation from circular)	0.056
Mean temperature (K)	88 (1 bar level)
Core temperature (K)	12 000
Visual geometric albedo (reflectivity)	0.46
Atmospheric components	97% hydrogen 3% helium 0.05% methane

Saturn's northern hemisphere defined by bright features from 43 million km by Voyager-2 on 12 July 1981 (Courtesy of JPL)



This view of Saturn's northern hemisphere, taken by Voyager-1 on 5 November 1980 from a range of 9 million km, shows a variety of cloud features. Small-scale convective clouds are visible in the brown belt; an isolated convective cloud with a dark ring is seen in the light brown zone; and a longitudinal wave is visible in the light-blue region. The smallest visible features are 175 km across. Such time-lapse sequences show how these storms evolve and allow the measurement of wind speeds. Winds blow mainly along lines of constant latitude on the gas giants. Near Saturn's equator, they blow eastward (with Saturn's rotation) at 500 m/s (Courtesy of JPL)



Saturn's system of rings and moons is vast, with rings labelled in order of discovery. The faint but far-reaching E-ring is many thousands of kilometres thick, but comprised mostly of micron-sized particles that are not a threat to Cassini (David Seal/JPL)

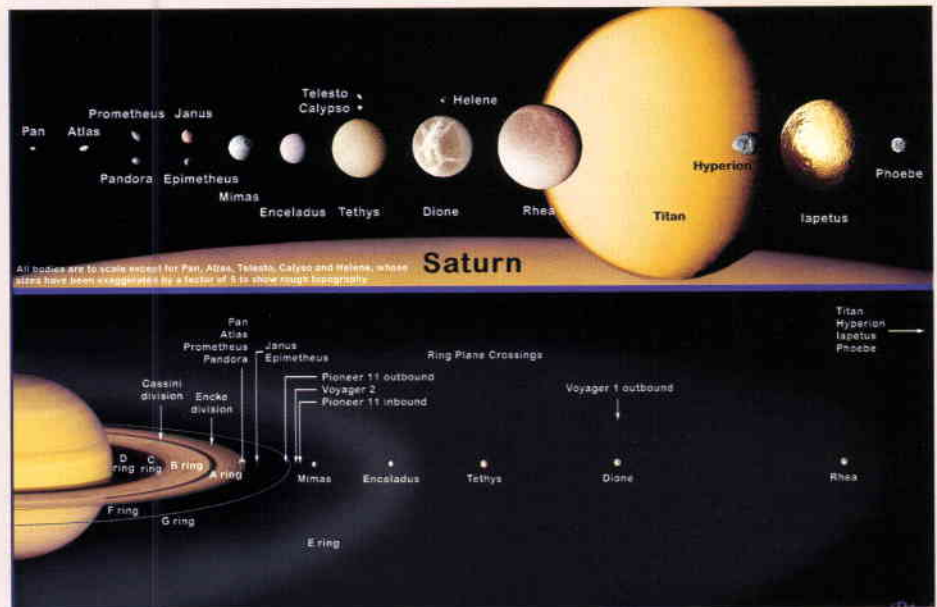
Saturn's Rings

Though various discoveries have been made over the past 330 years, it was the remarkable images returned by Voyager-1 and 2 in 1980 and 1981 that really made a quantum leap forward in our understanding of the rings. Cassini will help to answer the many questions raised.

Saturn's rings are a frigid cast of billions of particles and icebergs, ranging in size from that of fine dust to that of houses. The ring fragments are primarily loosely packed snowballs of water ice, but slight colourations suggest there to be small amounts of rocky material, possibly even traces of rust (iron oxide).

Although the distance from the inner edge of the C-ring to the outer edge of the A-ring is about 13 times the distance across the United States, the ring disc thickness is no more than 100 m (perhaps as small as 10 m!), with waves or 'corrugations' in this sheet rising and falling by a couple of kilometres. If a model of the ring sheet were to be made from material about the thickness of a coin, its diameter would need to be at least 15 km.

Numerous simple and complex patterns form within this rotating sea of icy fragments. They are variously

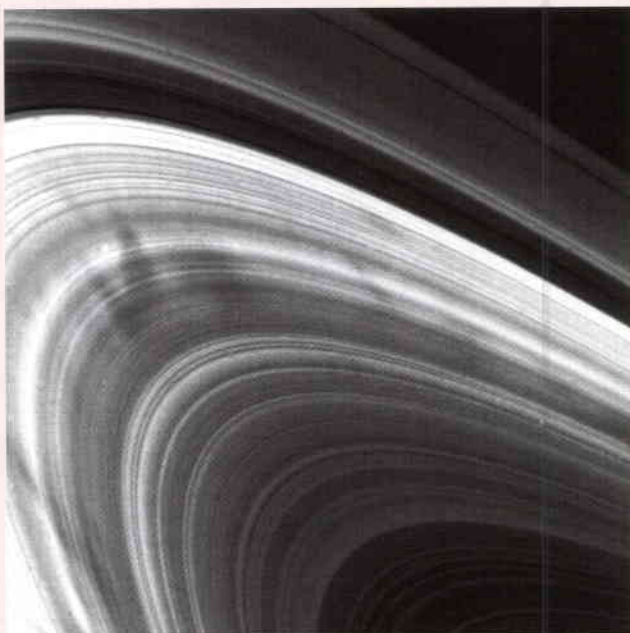


described as circular rings, eccentric rings, clumpy rings, resonance gaps, spokes, spiral density waves, bending waves and shepherding moons. There are, no doubt, also tiny moonlets too small for the Voyager cameras to have detected. The elaborate choreography of this complex ring system of patterns is produced and orchestrated by the combined gravitational tugs from Saturn and its moons that lie beyond the ring sheet, as well as by the tiny tugs from and gentle collisions with neighbouring particles.

How did the rings form in the first place? If one could collect all of the ring particles and icebergs into a single sphere, its diameter would not exceed about 300 km – roughly midway between the sizes of the moons Mimas and Phoebe. Are the rings simply leftover material that never formed into larger bodies when Saturn and its moons condensed aeons ago? Or, as is believed from Voyager data, are they the relatively young (within the last 100 - 200 million years) shattered debris from one or more broken worlds? The subtle compositional variations suggest that more than one parent body was broken apart.

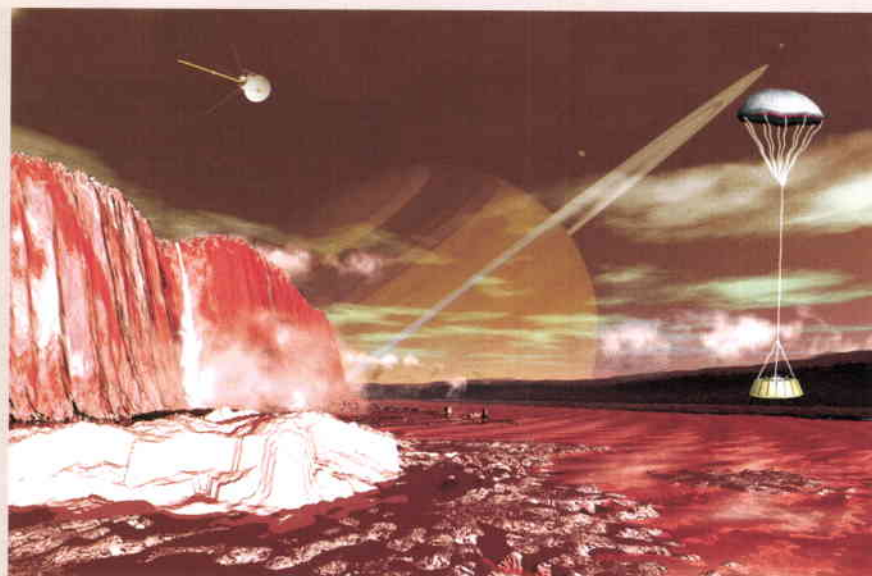
One explanation for the breakup argues that a body (either from within or outside of the Saturn system) passed close enough to the planet to be broken apart by tidal forces, but there would then need to be an energy-loss mechanism to allow the resulting fragments to be captured by Saturn. A more likely explanation attributes the breakup to impacts from meteoroids. If that theory is valid, small ring moons may still be awaiting disruption.

Numerous 'spoke' features appear in this Voyager-2 image of Saturn's rings. They are believed to arise from electromagnetic forces acting on charged dust grains that have been dislodged from ring bergs struck by meteoroids (Courtesy of JPL)



This view shows Titan's surface with Saturn dimly in the background through Titan's thick atmosphere of methane, ethane and (mostly) nitrogen. Cassini flies over with its HGA pointed at the Huygens Probe. Thin methane clouds dot the horizon and a narrow methane spring or 'methane fall' flows from the cliff at left and drifts mostly into vapour.

Smooth ice features rise out of the methane/ethane lake and crater walls can be seen far in the distance (David Seal/JPL)



Titan

Titan is possibly the most unusual moon in the Solar System. Larger than Mercury, more massive than Pluto and only slightly less massive than Jupiter's largest moon Ganymede, it has an atmosphere for some reason yet unknown with a surface pressure 1.5 times that of Earth's at sea level. Although scientists had speculated that Titan had some sort of atmosphere, few were prepared for the layers of hazes and clouds that prevented Voyager from making detailed surface observations. The first hints of surface detail have come from the Hubble Space Telescope, which noted a relatively IR-bright region 4100 km across in the southern hemisphere.

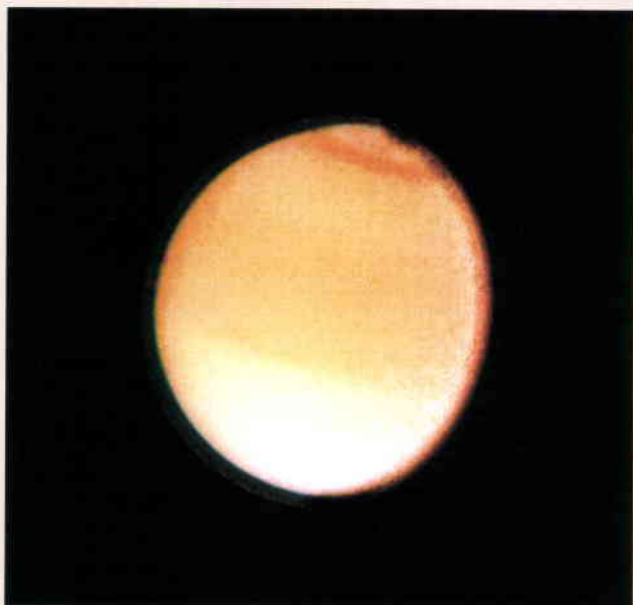
Titan is denser than Saturn's other satellites, possibly due to gravitational compression. Its composition is not precisely known, although its density suggests mostly water ice. Whether it is differentiated into layers or whether there is a molten core is not yet known. No magnetosphere was discovered by Voyager, so Titan might be geologically inactive.

Titan's atmosphere is composed primarily of molecular nitrogen (as is Earth's) with no more than 1% argon and a

few percent methane. There are also trace amounts of several other organic compounds (ethane, hydrogen cyanide, carbon dioxide, propane, acetylene, etc.). Other, more complex, chemicals in small quantities must be responsible for the orange colour as seen from space. It is suspected that the organics are formed as methane in the upper atmosphere is destroyed by sunlight. As high-energy particles and UV bombard the nitrogen and methane molecules in the upper atmosphere, these and further reactions could create a variety of organic molecules similar to the smog found over Earth's large cities, but much thicker. These molecules could then clump and rain slowly to the surface, where they may collect in pools, lakes or subsurface reservoirs.

In atmospheric terms, Titan is thought to represent conditions on the early Earth before life appeared. At the surface, Titan's temperature is a frigid 94 K. Water ice does not sublime at this temperature and so any water at the surface should not be part of the atmospheric chemistry. Nevertheless, there appears to be some kind of complex chemistry going on. Though life in any form familiar to us is unlikely to exist, due to the extreme cold, Titan may still provide us with information that could apply to the chemistry of early Earth.

It has been speculated that methane clouds produce a rain of liquid methane, resulting in large bodies of a liquid ethane/methane mixture up to 1 km deep. However, recent ground-based radar and Hubble Space Telescope observations make it clear that such global oceans are unlikely.



This Voyager-2 photograph of Titan, taken on 23 August 1981 from 2.3 million km, shows some detail in the cloud systems. The southern hemisphere appears lighter in contrast, a well-defined band is seen near the equator, and a dark collar is evident at the north pole. All of these bands are associated with cloud circulation in Titan's atmosphere. The extended haze, composed of submicron-size particles, is seen clearly around the satellite's limb (Courtesy of JPL)

The bright surface of icy Enceladus. In the foreground, an ice geyser projects a vapour jet into space. Enceladus may be the source of the E-ring (which can be very faintly seen along Saturn's equatorial plane); icy geysers may sustain the ring's supply of micron-sized particles (David Seal/JPL)



Icy Moons

All of Saturn's moons are likely primarily water ice with some rocky material, with the sizes and surface characteristics differing greatly, indicating widely ranging conditions during their formation and early existence. Some of the smaller irregular moons, such as Hyperion, might be the remnants of a larger satellite. Others inhabit the rings themselves, and might be leftovers from the cataclysms that created the rings.

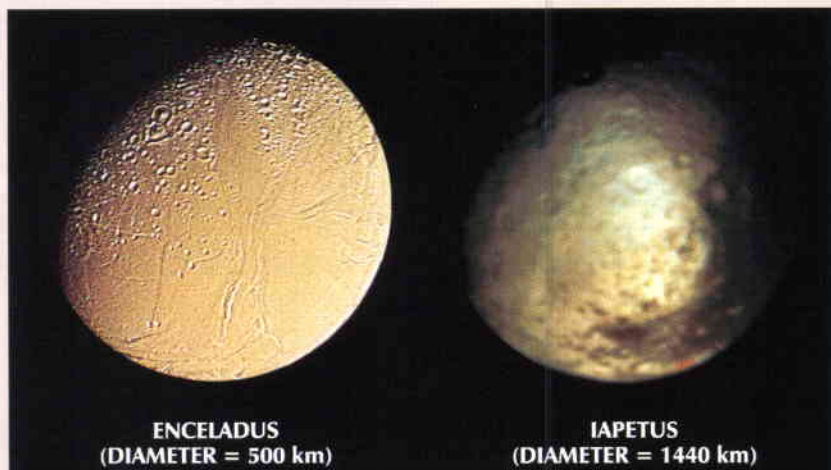
Most of the moons for which the rotation rates are known orbit synchronously, keeping one face towards Saturn. This frequently leads to a dramatic difference between the leading and trailing hemispheres. Iapetus has an extremely dark leading hemisphere, and a brightly reflective trailing hemisphere. This dichotomy was first noted by Cassini, who observed that the satellite was visible only on one side of its orbit. Dione is remarkably free of large impact craters on its trailing hemisphere, probably due to a combination of being sheltered from impact gardening and the escape of icy fluids onto the surface through cracks in the crust, leaving the giant crisscrossing, wispy, bright marks observed by Voyager. Rhea shares many of Dione's characteristics.

Enceladus also shows the results of some kind of icy volcanism, with relatively smooth regions interrupting the otherwise cratered terrain. In addition, linear sets of grooves over 100 km long traverse the surface, probably due to faulting caused by crustal deformation, implying that Enceladus may have undergone relatively recent internal melting. Its relatively new surface makes it the brightest of Saturn's moons.

All of the moons show some level of impact cratering, with Mimas being perhaps the most dramatic example. The large impact crater Herschel on Mimas (130 km diameter) was the result of a collision that nearly shattered the moon. Tethys also boasts an immense (400 km) crater. Tethys must have been at least partly liquid to absorb the impact without breaking up. It is speculated that many of the moons may have been shattered and gravitationally reassembled many times in their early geological history. Tethys contains Ithaca Chasma, a huge trench, 100 km wide, stretching across three quarters of its circumference. This feature may have been formed when Tethys solidified and expanded, cracking the crust.

There are complex gravitational tidal resonances between some of Saturn's moons, and between some moons and the ring system. The 'shepherding satellites' – Atlas, Prometheus and Pandora – appear to help keep the rings in place. Mimas may be responsible for the lack of material in the Cassini Division. Pan is in the Encke Gap. Tethys has Telesto and Calypso caught in the region of its Lagrange points. Helene orbits in Dione's leading Lagrange point. Janus and Epimetheus also nearly share an orbit, apparently switching places every four years or so.

Three pairs of moons – Mimas-Tethys, Enceladus-Dione and Titan-Hyperion – maintain stable relationships between their orbits, due to their gravitational interaction. The ratio of



ENCELADUS
(DIAMETER = 500 km)

IAPETUS
(DIAMETER = 1440 km)

Some of the interesting variety among Saturn's many known icy satellites is revealed in these Voyager-2 images. Enceladus' bright, relatively uncratered terrain is coated with water ice. The smooth areas suggest that internal heating has melted portions of the surface, possibly even leading to eruptions feeding Saturn's tenuous E-ring. Iapetus, on the other hand, has a leading face as dark as asphalt, while its trailing face is six times brighter. The dark side is presumably some type of carbon-based material, but was it swept up as the moon orbited Saturn or did it rise from the moon's interior? (Courtesy of JPL)

Mimas' orbital period to Tethys' is 2:1, as is Enceladus:Dione. Titan's and Hyperion's orbits are in a 3:4 resonance. These resonances can result in tidal heating of the moons, although it is not believed that this process alone could account for the icy volcanism that may exist on Enceladus.

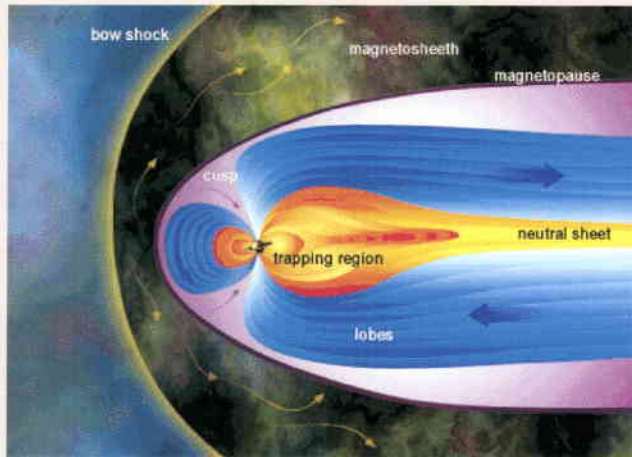
While the majority of Saturn's moons orbit nearly in the plane of its equator, Iapetus' orbit is inclined almost 15°. Phoebe's orbit is upside down, with an inclination of

almost 175°. It is possible that Phoebe may be a captured asteroid or a comet remnant.

In addition to the 18 named satellites, at least a dozen more have been reported and given provisional designations, although none has yet been confirmed.

Saturn's Magnetosphere

Saturn's magnetic field is probably generated by the planet's rotating layer of liquid metallic hydrogen. Equatorial ring currents as high as 10^7 A flow inside the resulting magnetosphere. The magnetic field is about 0.21 gauss at the cloud tops. Unlike most planets with magnetic fields, however, Saturn's dipole lies within 1° of its spin axis. This has important implications because dynamo theory requires some offset to permit regeneration of the magnetic field. Other Cassini objectives are to improve understanding of the source of the planet's intermittent radio bursts, as well as the many interactions among Saturn's magnetic field and the rings, moons and solar wind.



Saturn's magnetosphere and its major features (Courtesy of Univ. of Michigan)

THERE IS A STAR IN SWISS SPACE TECHNOLOGY



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Ulysses 7 Years On — Operational Challenges and Lessons Learned

A. McGarry* & N. Angold**

ESA Ulysses Mission Operations Team, Jet Propulsion Laboratory, California, USA

History

The initial idea for a spacecraft which would orbit the Sun's polar regions was first proposed in 1959 by a group of interdisciplinary scientists, many of whom later became investigators with payloads on Ulysses. However, it was not until the early 70's that propulsion and mission design technology had advanced to the stage to make such a mission possible. In the mid-70's, Pioneer 10 and 11 visited Jupiter and Saturn, thus proving the concept of using planetary bodies to provide a

gravitational 'slingshot' to spacecraft as they flew past. This allowed mission designers to plan orbital trajectories to greater distances and inclinations than would be possible by conventional means alone, and within reasonable timescales.

The Ulysses mission, being a joint collaboration between ESA and NASA was initially planned as two spacecraft, one from each agency. Ulysses had to survive programme cuts, mission re-designs, programme cancellation and resurrection, and the Challenger disaster before finally being launched on 6 October 1990.

* Vega Group PLC, United Kingdom
 ** Directorate of Technical and Operational Support, ESOC, Darmstadt, Germany

Although the Ulysses mission is currently only one third of its way through its second orbit of the Sun, it is worth remembering that this very successful mission was launched 7 years ago. Many current and future missions with ESA participation (e.g. Hubble Space Telescope, ISO, SOHO, Cassini/Huygens, Rosetta) have one or more of the following in common with Ulysses: interplanetary-type trajectories; missions of long duration; multidisciplinary science; cooperation with other international space agencies. It would therefore seem prudent to pass on some of the lessons learned in these areas from the first 7 years of Ulysses operations.

Mission summary

The goal of the Ulysses mission was to fly over the Sun's northern and southern poles at solar latitudes above 70° . This could only be achieved by first sending the spacecraft on a fast 16-month trajectory to Jupiter, using the planet's gravitational force to divert Ulysses into a new, high-inclination orbit around the Sun (see Fig. 1).

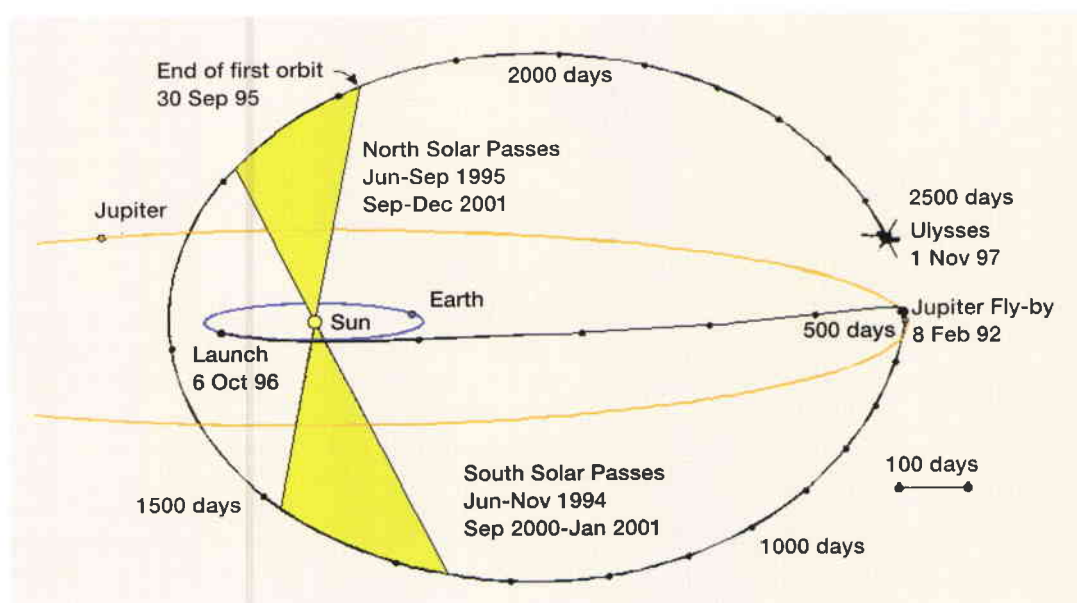


Figure 1. The Ulysses orbit

New challenges

What will be the challenges facing spacecraft systems and operations engineers working on future missions for ESA? The design of the Ulysses spacecraft and its mission profile introduced its Mission Operations Team to several areas of space hardware and operational considerations never (or rarely) experienced on ESA missions:

- **Deep space environment.** Ulysses would operate at heliocentric ranges varying between 1 and 5.4 astronomical units, thus exposing it to a solar flux varying between 1400 Wm^{-2} and 45 Wm^{-2} . This would very significantly affect the thermal subsystem during each orbit.
- **Deep space communications.** Command transmission and telemetry reception would take place at geocentric ranges of 1 AU to 6.3 AU. This would have to be done using the NASA Deep Space Network (DSN).
- **A nuclear power source.** Due to the large solar range, Ulysses had to use a Radioisotope Thermoelectric Generator (RTG). This converts the heat generated by the decay of nuclear material directly into electrical power.
- **Space Shuttle.** Ulysses would be launched on the Space Shuttle Discovery along with an upper stage consisting of an Inertial Upper Stage (IUS) and the Payload Assist Module (PAM). These upper stages would impart the required velocity to send Ulysses on a fast track to Jupiter.

Lessons learned

What has the Mission Operations Team gained from dealing with the challenges presented to them by Ulysses? This section summarises the many and diverse lessons learned so far.

Interplanetary space

Launching a spacecraft out of the sphere of the Earth's influence brings with it a host of new considerations for spacecraft operations. The effect of the deep space environment on spacecraft subsystems (especially power, thermal and TT&C), as well as the ground segment and planning and scheduling functions must be thoroughly understood. The major drivers are as follows:

One Way Light Times (OWLT)

At the maximum geocentric range of about 6.3 AU, Ulysses would experience OWLTs of 53 minutes. Traditionally, ESA missions use Flight Operations Procedures (FOP) to control spacecraft, but such long OWLTs make the use of FOPs very difficult. Procedures become very elongated, especially if commands have to be confirmed before proceeding further. While Ulysses daily operations were initially based on

a set of FOPs, they have evolved into a daily command form based on a set of routine operations. Any periodic platform operations or experiment command requests are then added to the daily command form as required.

Another effect of the OWLT is a reliance on onboard safety and protection logic. Spacecraft rely on autonomous monitoring for safe operation of the power or attitude control subsystems. An additional concern for Ulysses was the thermal safety of the spacecraft, especially for the propellant in the Reaction Control System. During major power reconfigurations, thermal changes can occur quite quickly and reaction times, extended by the OWLT, can be long enough to allow temperatures to rise or fall outside of safety limits.

Power and thermal subsystems

In deep space the power and thermal subsystems will provide many, or perhaps all, of the mission drivers. Typically, the solar range changes greatly during the mission causing a large variation in the solar flux, thus affecting the thermal control of the spacecraft. Spacecraft which use advanced solar arrays for power will still receive reduced solar energy at large solar distances due to the $1/R^2$ effect. While providing power independent of solar distance, an RTG has a fairly low output (for Ulysses just 285W at beginning of mission) which decays, albeit in a fairly predictable fashion, throughout the mission. Either way, available power is a precious resource requiring careful allocation and management. Many passionate and energetic discussions took place in Ulysses meetings over the matter of a couple of watts of electrical power!

Telecommunications in deep space

Communications over large geocentric distances require a detailed understanding of the link budget. The Ulysses Mission Operations Team has frequently had to predict future link budgets and continuously monitor the performance of the TT&C subsystem.

Due to its trajectory and fast passage to Jupiter, Ulysses achieved large velocities relative to the Earth. This affected the uplink and downlink frequencies due to Doppler shifts. When difficulties were experienced in commanding Ulysses on 1 February 1991, it took a concerted effort by ESA spacecraft engineers and NASA ground segment engineers to find the exact adjustments needed to compensate for the Doppler effect. Partial commanding was regained after a few days, and full commanding capability was restored on 12 February.

The importance of the ground segment - a shared resource

NASA's Deep Space Network is a heavily used resource supporting many spacecraft in flight, launch campaigns, Space Shuttle missions and even ground-based observations such as high-powered radar and Very Long Baseline Interferometry.

Timely scheduling of antenna time is therefore critical. The use of shared resources demands early inputs by its users. Conflicts have to be identified early on so that solutions can be found and agreed upon.

At interplanetary ranges, the ground segment has a large effect on the planning, scheduling and execution of operations. The Mission Operations Team had to understand the influence of the ground segment on spacecraft operations. Some examples were:

- Should an operation be executed by real-time command or time-tagged to execute at an exact time?
- If command capability was lost today, how long could routine operations continue?
- Should we risk playing back some data at a higher bit rate even though the link margin is low and there is a possibility of bad weather at the station?

Having to share resources with other missions (no dedicated antenna) means that there can be an operational impact from the ground segment. Examples include:

- ground-segment equipment failures
- 'acts of God', e.g. earthquakes, extreme weather such as snow or lightning strikes
- other spacecraft with problems - a 'spacecraft emergency' is declared and your antenna time is reassigned
- frequent modifications and software changes needed to satisfy mission requirements from some or all of the overall user community.

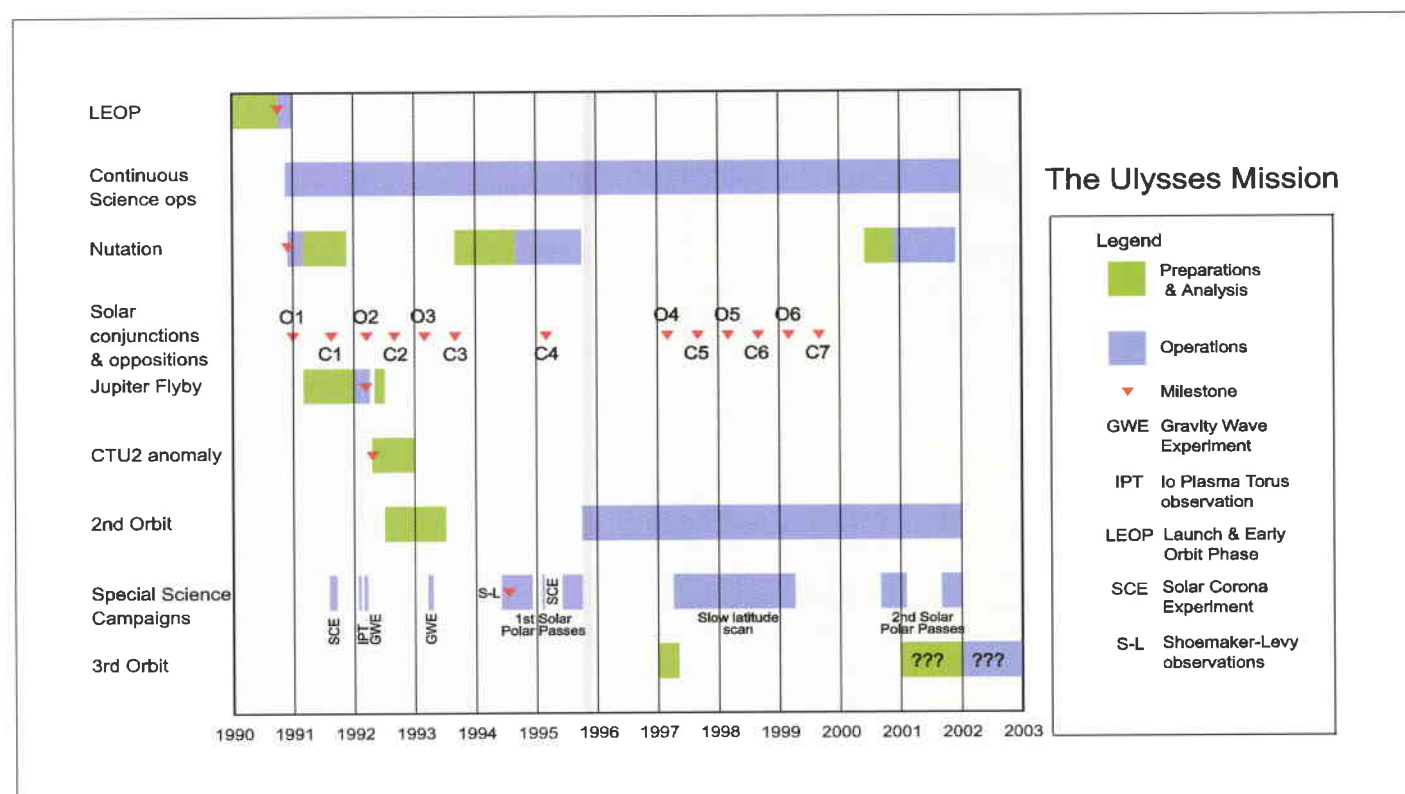
Operational flexibility is needed to cope with such resource losses. For example, in June 1993, a critical bearing of the DSN Standard 34 metre antenna in Madrid (DSS 61) failed. The resulting repairs lasted until mid-August and meant that the DSN had to serve its community with reduced capability. Even with additional coverage provided by the emergency use of the Weilheim 30 metre antenna in Germany, the Ulysses project lost a significant amount of tracking time. During this period, the rate at which the data was recorded on board the spacecraft was often reduced from 512 bps to 256 bps in order to avoid gaps in recorded data. Although this meant lower amounts of data overall, greater continuity of data was achieved, a trade-off the scientists preferred to make.

Long duration missions

Activity level

Figure 2 details the Ulysses Mission Operations Timeline. Normally, after the Launch and Early Orbit Phase (LEOP), mission operations tend to settle down to a more routine nature,

Figure 2. Ulysses mission operations timeline



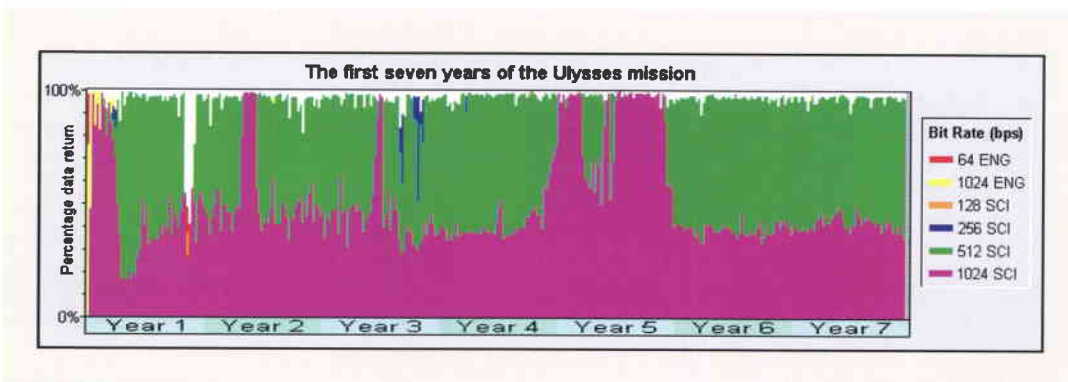
punctuated by the (hopefully) occasional anomaly. With Ulysses, there have been numerous activities to plan for and execute, many of them running in parallel. The LEOP phase, while very successful, uncovered the Nutation anomaly. Recovery from this and the subsequent investigation had to be balanced with the preparations for the Jupiter Flyby. Post-Jupiter checkouts revealed a significant anomaly in the redundant Central Terminal Unit (CTU2) which required further investigation and analysis. This began to overlap with efforts for the justification of a second orbit, swiftly followed by preparations for the first set of Solar Polar passes, and the associated return of Nutation.

Team stability

In a mission of such long duration, this busy and varied level of activity has been good for the Mission Operations Team. The interest level and the workload have remained high and this

Before launch, it was assumed that an eight-hour pass per day would be sufficient to return eight hours of 1024 bps data. Once Ulysses was flying, however, it became obvious that there were significant periods (particularly at the beginning of a track) when 512 bps was required during each track to ensure that data continuity was maintained. Hence, there was not enough time to play back recorded data using a bit rate which would also provide the required 1024 bps real-time data. The resulting reduction in science data return was tremendous. Therefore, the Science Working Team passed a resolution at its meeting in Heidelberg, Germany, in April 1991, urging the two agencies to find a way to restore the expected data return. This was quickly achieved by increasing the Ulysses tracking requirements to ten hours per day. As a result, Ulysses has provided the heliospheric science community with not only a unique data set, but one of outstanding quality and consistency.

Figure 3. Ulysses mission data return



is reflected in the great morale and enthusiasm of the team, and the low staff turnover. One example of the benefits of having a well motivated team can be seen in the consistently high data return for the mission, shown in Figure 3.

The stability of the team has benefitted the mission as a whole since mission-specific expertise and knowledge is retained. This tends to reduce the number of times you 're-invent the wheel' when a problem arises.

Mission objectives

Ulysses was designed to provide a continuous set of science data between solar latitudes of $\pm 80^\circ$ (Fig. 3). Ulysses has consistently met and exceeded its mission goals of an average of 95% data return, with 33% of the data being at the higher data rate of 1024 bps. This has been achieved through the combined efforts of the members of the ESA and JPL Mission Operations Team who have worked closely to optimise the data return, and the DSN for providing such good support.

Software and hardware issues

Due to the length of the Ulysses mission and the rapid developments in computer hardware and software, the Ulysses Monitoring and Control System (UMCS) was in danger of running outdated software on unsupported hardware. Effort has therefore been devoted to developing new monitoring and command software using modern hardware which will ensure compatibility until the end of the mission.

Multidisciplinary science

A unique data set

Ulysses is providing the heliospheric science community with a unique set of field, particle and wave data over the complete latitudinal range of the Sun, and over ranges of 1 to 5.4 AU. With the Second Orbit, it will also have studied the Sun over one full 11-year cycle, thus observing the Sun during its minimum and maximum periods of sunspot activity.

Science trade-offs

Some trade-offs may be necessary when a single spacecraft is providing a platform for

various experiments. A large part of the preparations for the Jupiter flyby were dedicated to ensuring that there was enough power available to guide the spacecraft safely through the Jovian radiation belts, at a time when the spacecraft was at its maximum heliocentric range (i.e. it was cold) but the onboard experiments were expected to use their peak power levels.

Another consideration is that some instruments are more sensitive to data rate changes than others, depending on how they acquire, process and transmit their data.

Flexibility

Extra science opportunities may arise during a mission, which were not planned for or anticipated in the design phase. Ulysses was able to perform additional Radio Science observations during the Joint Gravity Wave Experiment in March-April, 1993 and the Fast Latitude Scan of the Solar Corona in February-March, 1995. The STO experiment was also configured to listen for radio emissions during comet Shoemaker-Levy's collision with Jupiter in July 1994.

International cooperation

While bringing many benefits to both ESA and NASA, the joint partnership involved in running the Ulysses mission has also brought with it some management challenges*. Means have had to be found for coping with:

- cultural and management differences
- communications difficulties associated with the geographical locations involved and time-zone differences
- the maintenance of equality between the agencies.

Management

At the highest inter-agency level, the cooperative components of the mission were bound together by the Memorandum of Understanding (MOU) signed by both ESA and NASA. Each agency provided a Project Manager and a Project Scientist, who had their associated 'chains of command'. However, to be a truly cooperative project, ways had to be found for the two sides to work together not only at agency level, but at all levels. This has been achieved by the formation of a decision-making body and various types of regularly scheduled meetings:

- **The Joint Working Group (JWG)** is made up of the Project Managers and the Project Scientists from both agencies, along with the Mission Operations Management. Others may be invited to attend to present particular topics as needed. This forms the basic decision-making body for the project.

- **The Science Working Team (SWT)**, chaired by the two Project Scientists, meets twice a year, with the venue alternating between the USA and Europe, providing a convenient forum for both scientists and the operations teams to meet. The scientists present and discuss preliminary results; the Mission Operations Team reports on spacecraft and ground segment activities and any possible impacts to science teams. This frequent contact has facilitated discussion and promoted problem-solving processes. For convenience, the JWG has traditionally gathered at some point during each SWT.

- **The Daily Operations Meeting** is held every work day at the Ulysses Mission Support Area (MSA) in JPL. This meeting provides the working interface between the operations teams from ESA and NASA. The majority of operational problems are identified, discussed and solved at this level. However, if this is not possible, then they can be raised to higher levels within the appropriate agency for discussion, and, ultimately, may be decided upon by the JWG.

This structure has evolved into an efficient way of dealing with the inevitable small problems which 'crop-up' from time to time in running an international, interplanetary spacecraft mission.

Integration

Another contribution to the smooth operation of the Ulysses mission was the fusing of the ESA and JPL staff into an integrated Mission Operations Team. This team is headed by an ESA staff member as Mission Operations Manager with a JPL staff member in the role of Deputy. Operational responsibilities are divided into spacecraft operations (headed by an ESA Spacecraft Operations Manager) and ground segment operations (headed by a JPL Ground System Manager). Their respective teams are drawn from each organisation.

Co-location

Co-location of the ESA and NASA elements of the Mission Operations Team at JPL has been central to the success of the Ulysses Mission, thus far. While modern communications can go a long way towards helping international teams to work together, a single location enabled the ESA and JPL staff in the integrated Mission Operations Team to develop a close working relationship. This has frequently resulted in the fast resolution of real-time problems and a consequent improvement in data return.

The inclusion of staff assigned to Ulysses for mission scheduling of antenna and network time and for resource negotiation has been an

*Ulysses - An ESA/NASA Cooperative Programme, W. Meeks and D. Eaton, ESA Bulletin No. 63, August 1990

and

Operational and Communication Challenges during the Ulysses Odyssey, P. Beech, 47th International Astronautical Congress 7-11 October, 1996 Beijing, China.

important factor. In these days of the 'multi-mission' approach to so many services, dedicated staff who know the technical aspects of the mission and who are personally committed to the overall goals of the project have greatly benefitted Ulysses.

Preparations

With so much resting on cooperation between international partners and the extensive use of shared resources, it was always clear that advanced preparations would be a key to mission success. However, a flexible approach was also needed to cope with the realities of real-time operations in a shared-resource environment.

For spacecraft operations this meant that requirements had to be defined well in advance in order to schedule the necessary ground-segment resources. However, allocations had to be continuously reviewed since activities could be impacted by events such as launches (which have higher priority), equipment failures and spacecraft emergencies.

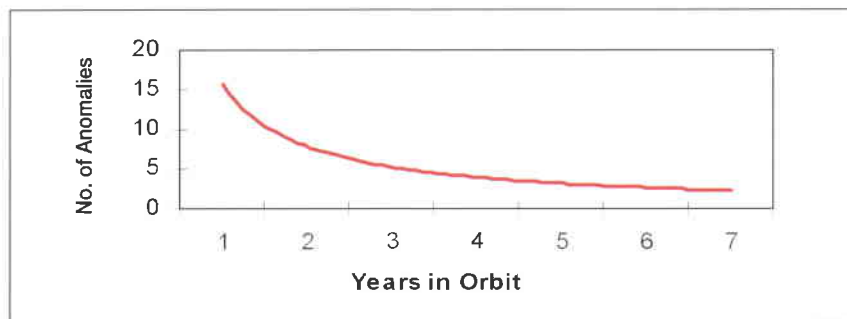


Figure 4. The decreasing trend in the number of anomalies means long-term reliability for Ulysses

This need for early preparation translated into a busy workload for the Mission Operations Team. In addition to ensuring that routine operations achieved mission goals, future preparations were also ongoing.

Miscellaneous lessons learned

The Mission Operations Team members were cross-trained to learn each other's skills. This gives greater flexibility in meeting operational support requirements, and eases staffing problems during holidays or illness.

Outreach has become an important 'product' of today's missions. It can range from creating a Web site* with public access, giving lectures at local schools and colleges, designing and staffing museum exhibits, to giving visitors tours of the workplace.

Continuing self-assessment has been a beneficial activity. Review your way of doing things - is there room for improvement? Are there any persistent or repetitive problems? Visit other operations teams and see how they

do things - you'll either learn something new or confirm that you are doing things well!

Spacecraft

Ulysses has proven to be very robust, enabling it to cope with severe anomalies such as Nutation and the CTU2 problem, and to be run by a small operations team. When needed, excellent post-launch support was provided by both the project and industry, especially for the resolution of major anomalies. The rate of occurrence of anomalies has markedly decreased since the first two years of operations, as shown in Figure 4, and the propulsion system has demonstrated remarkably low gas generation rates**. The reliability and longevity of Ulysses have given it the potential to operate for a second and possibly third orbit.

Ulysses improvements

After seven years of successful operations, the Mission Operations Team has become very familiar with Ulysses. Seeking to use those long round-trip light-times, waiting for command confirmations, more productively and with the luxury of hindsight, we have often discussed what we would like to see in a 'Ulysses-2'.

A simulator would be useful in order to practise new procedures, rather than peer review followed by live tests. The inclusion of a 'time-tag buffer' has allowed routine activities to be loaded ahead of time on the spacecraft, thus reducing the real-time operations load. However, a larger one would be useful. More telemetry parameters would be valuable, especially to assist in the monitoring of the RTG power and thermal subsystem, and in the analysis of autonomous operations. The removal of imaging capability during the early design of the mission (due to budget constraints) may have reduced public awareness of the Ulysses mission. The ability to play back data more than once from the tape recorder would provide the opportunity to recover some data losses.

Conclusions

Ulysses is already a very successful mission. Hundreds of papers have already been published in scientific journals, several publications have dedicated special issues to Ulysses science, and scientists from many other missions are using Ulysses data. Ulysses is now well into its second orbit and feasibility studies have indicated that a third orbit is not only possible, but would continue to provide new and exciting data for scientists, and would challenge the skills of the Mission Operations Team.

*<http://ulysses-ops.jpl.nasa.gov/~ulsfct/index.htm>

**Inflight Performance of the Ulysses Reaction Control System, A. McGarry, W. Berry & D. Parker, Second European Spacecraft Propulsion Conference, ESA SP-398, May 1997.

The Heliosphere in Perspective - Key Results from the Ulysses Mission at Solar Minimum

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Introduction

The Sun's expanding outer atmosphere, the solar wind, carves out a bubble in the surrounding interstellar medium which we call the heliosphere. The pole-to-pole exploration of the heliosphere by the Ulysses mission, an international collaboration between ESA and NASA, has been a spectacular success, not only for its scientific discoveries and technological achievements, but also for the excellent collaborative spirit within the project and science teams.

On 30 September 1995, five years after launch, Ulysses completed the first phase of its highly successful exploratory mission to study the Sun's environment from the unique perspective of a solar polar orbit. The ESA-built spacecraft is the first ever to investigate the region of space above the Sun's poles, passing over the south pole in mid-1994, and the north pole one year later. The scientific data returned by the nine experiments on board Ulysses have literally added a new dimension to our view of the Sun's environment, the heliosphere. The breadth of scientific topics addressed by the mission is truly impressive, ranging from detailed measurements of the solar wind and its magnetic field, to the properties of interstellar gas and the isotopic composition of cosmic-ray nuclei. Most of these seemingly diverse phenomena co-exist in the heliosphere, and a major contribution of the Ulysses observations is the very specific constraints they place on our physical description of this environment. In this article, we summarise the key findings of the mission to date, and discuss the exciting results to be expected from the second phase of Ulysses' out-of-ecliptic journey. The novel operational challenges of the mission and the lessons learned to date are discussed in the companion article in this issue by A. McGarry and N. Angold.

Launched by the Space Shuttle Discovery in October 1990, Ulysses' primary objective was to characterise, for the first time, the properties of the Sun's environment at all latitudes from the equator to the poles, and at distances ranging from 1 to 5.4 astronomical units (1 astronomical unit (AU) is the Sun-Earth distance, 150 million km). The scientific

investigations address a wide range of heliospheric phenomena, including the solar wind, the heliospheric magnetic field, energetic particles and cosmic rays, natural radio emissions, interstellar gas and dust, and gamma-ray bursts.

The timing of the launch, and the requirement to use Jupiter's gravitational field to catapult the spacecraft into its final solar-polar orbit, resulted in the high-latitude part of the mission taking place under near-quiet solar conditions. Phasing the mission this way was the preferred option scientifically, although as a result of several lengthy delays, the actual launch date was ultimately determined by circumstance rather than design.

In the seven years since launch, Ulysses has provided an unprecedented perspective of the heliosphere around solar minimum. As noted above, the quality of the results has been enhanced by the excellent international cooperation between NASA and ESA and by the involvement of investigators from the larger space science community. The Ulysses observations obtained so far have resolved a broad range of questions in the space sciences, due in large part to the unique orbit of the spacecraft. They have also raised questions unanticipated from our previous knowledge of the heliosphere, and provided a firm base on which to continue our exploration. The purpose of this article is firstly to highlight the major findings of Ulysses' 'solar minimum mission', and secondly to look ahead to the equally exciting opportunities offered by the 'solar maximum mission'.

Scientific highlights

The scientific accomplishments of Ulysses to date have been reported in more than 700 publications covering a wide range of solar,

heliospheric and astrophysical phenomena (see also ESA Bulletins 67, 72 and 82). These accomplishments include the following:

- The characterisation of two distinct solar wind states, a fast high-latitude wind which only occasionally extends down to low latitudes, and a slow low-latitude wind centred about the heliospheric current sheet. These are separated by a sharp boundary extending from the corona down to the chromosphere.
- The discovery that the magnitude of the radial component of the heliospheric magnetic field does not increase towards the poles. The constancy of the radial field implies that the dipole-like configuration of the Sun's surface field is not maintained and that as a result, the polar solar wind

undergoes significant non-radial expansion.

- The discovery that co-rotating solar-wind stream structures with forward and reverse shock waves, well-studied at low latitudes and expected to be confined to those regions, produce effects extending to the highest latitudes explored by Ulysses. These effects include the recurrent modulation of galactic cosmic rays and injection of accelerated lower-energy particles into the polar regions, suggesting a revised global structure for the heliospheric magnetic field.
- The discovery of a new class of forward-reverse shock pairs associated with coronal mass ejections (CMEs) at high latitudes. Over-expansion of the CME caused by internal pressure is the source of these shocks.
- The discovery that the influx of cosmic rays at high latitudes is smaller than predicted for this phase of the solar activity cycle.
- The determination of the flux and flow direction of interstellar dust grains passing through the Solar System.
- The measurement of the flow parameters of interstellar helium, leading to an improved description of the motion of the Solar System through the local interstellar cloud.
- The derivation of the density of interstellar atomic hydrogen and helium, leading to improved knowledge of the interaction of the local interstellar cloud with the heliosphere.
- The first-ever measurement of the interstellar $^3\text{He}/^4\text{He}$ ratio, the value of which suggests that the amount of dark matter produced in the Big Bang was greater than previously thought.
- The measurement of individual isotopes of cosmic-ray iron and nickel, showing a source composition that is generally consistent with Solar System matter. This suggests that cosmic rays are accelerated in the interstellar medium rather than being the products of explosive nucleosynthesis.
- The determination of the positions of gamma-ray bursts with unprecedented accuracy, including a contribution to the first plausible identification of an optical counterpart.

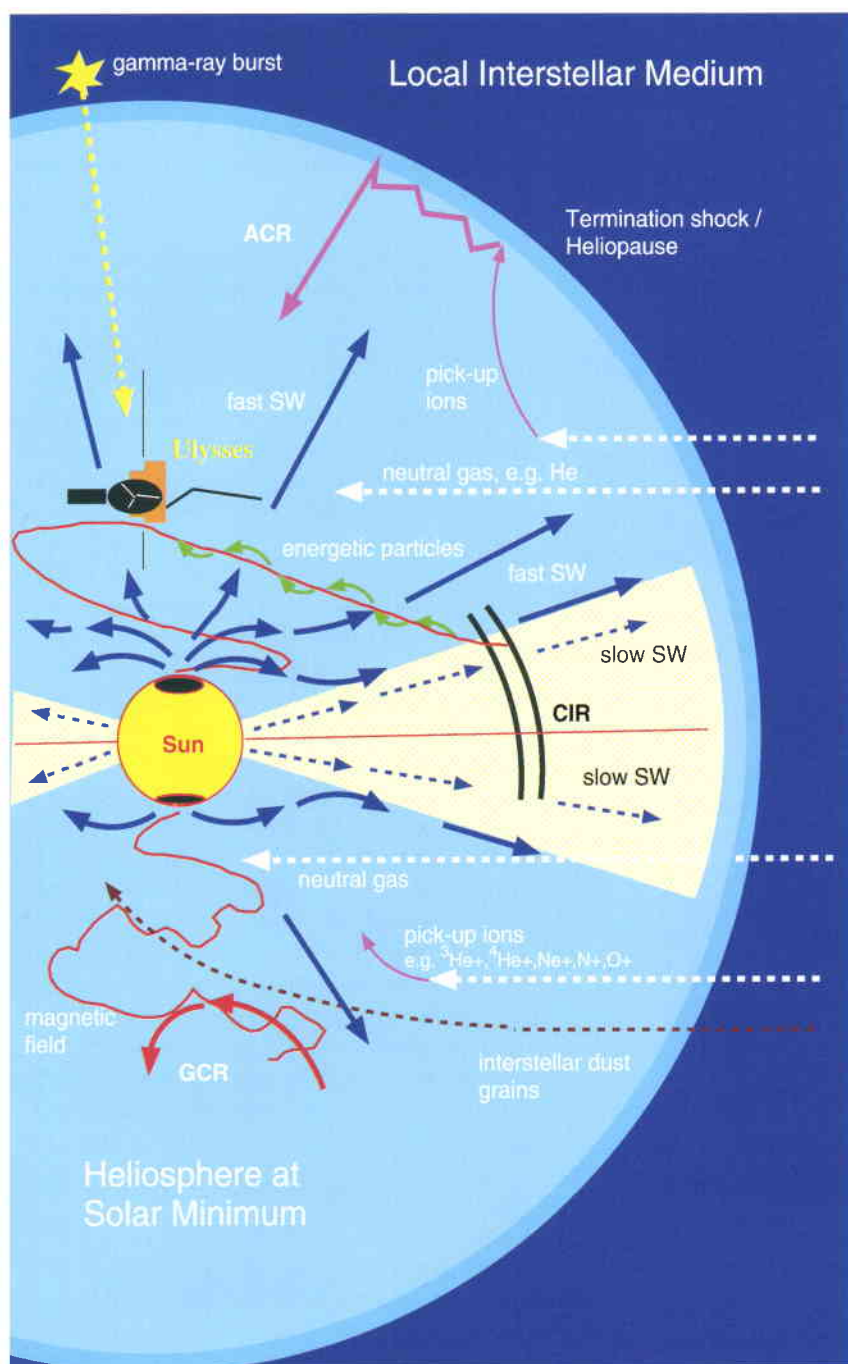


Figure 1. Schematic showing new aspects of the heliosphere at solar minimum as revealed by Ulysses. Among the phenomena depicted are: (a) fast solar wind filling the bulk of the heliosphere, separated from the near-equatorial slow wind by a relatively sharp boundary; (b) interstellar neutral gas, the source of pick-up ions which in turn form the anomalous cosmic-ray component (ACR); (c) co-rotating interaction regions (CIR), giving rise to periodic variations in the intensity of energetic particles and cosmic rays up to high latitudes; (d) gamma-ray bursts; (e) the heliospheric magnetic field, with enhanced fluctuations at high latitudes scattering incoming cosmic rays, and field lines connecting high and low latitudes; (f) interstellar dust grains

In the following sections, we will describe a number of these findings in more detail.

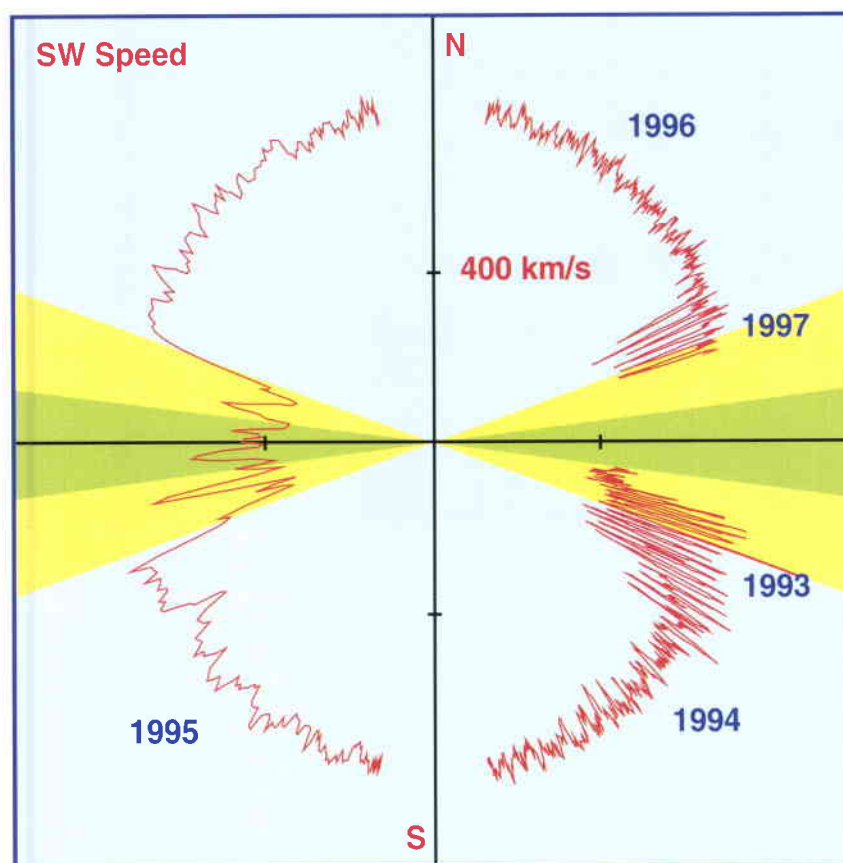
Global heliospheric structure

One of the main goals of the Ulysses mission was to determine the global structure of the heliosphere, in particular with regard to the distribution of solar-wind plasma, and its 'frozen-in' magnetic field. The latitude survey carried out by Ulysses, the first ever, has resulted in the following picture (Fig. 1) of the heliosphere at solar minimum. The three-dimensional structure is characterised by a basic north-south symmetry, and is dominated by the presence of the fast solar wind from polar and high-latitude regions that expands to occupy a large fraction of the heliospheric volume. The slow wind, shown by Ulysses to be the 'exception' rather than the 'rule' (as was previously thought), is confined to low latitudes. Observations made by Ulysses during its rapid pole-to-pole transit near perihelion have revealed that the transition from slow to fast wind is surprisingly abrupt. This is graphically illustrated in Figure 2, which shows a polar plot of the solar-wind speed measured by Ulysses as a function of heliolatitude.

Note that nearly all other space missions have been confined to the narrow region of the heliosphere at low latitudes dominated by slow wind, and that Ulysses has provided the first direct, detailed view of the 'true' solar wind flowing from the polar coronal holes. This fast-flowing solar wind has been found by Ulysses to be relatively constant near solar minimum, with a speed of approximately 750 km/sec. On the other hand, while clearly much less variable than the low-latitude slow wind, closer inspection has shown that even the fast wind is far from quiescent. New observations from the SOHO spacecraft present a picture of the solar atmosphere that, even at solar minimum, is highly dynamic and clearly reflected in the Ulysses solar-wind data. For example, Ulysses discovered so-called 'microstreams', which may be related to the polar plumes observed to emanate from polar coronal holes.

The Ulysses magnetic-field measurements indicate that the radial field component, and consequently the magnetic flux, are independent of latitude. This has led to the unanticipated conclusion that the magnetic-field pressure controls the solar-wind flow near the Sun, driving a non-radial expansion by more than a factor of 5 from the polar coronal holes. Another characteristic property of the fast high-latitude wind that has been revealed by Ulysses is the continual presence of large-amplitude transverse waves in the magnetic

field. The wave amplitudes typically equal or exceed the magnitude of the background field and, as such, are an example of strong turbulence. The waves are observed over a wide range of periods; the longer period variations probably originating in the 'random walk' of field lines at the Sun, which in turn is a signature of the non-quiescent solar surface.



Although the spiral magnetic-field structure predicted by the earliest models of the solar wind is preserved to the highest latitudes, a significant departure from this so-called 'Parker' field configuration has been discovered. A likely explanation is that the observed deviations are the result of the large-amplitude waves referred to above.

Ulysses observations of solar radio bursts, which are relatively rare at solar minimum, provide a capability for remote-sensing of large-scale magnetic-field structures. As the electrons responsible for the radio emission stream out along the magnetic field lines, they provide an 'image' of the field lines in the inner heliosphere.

In particular, the high-latitude observations of these radio bursts from Ulysses alone provide the 2-D image shown in Figure 3. Significant distortions of the field lines — for example, by a transient structure in the solar wind — can be readily detected in the trajectory of the radio burst.

Figure 2. Polar plot of solar wind speed, as measured by the SWOOPS experiment on board Ulysses, versus latitude. Time runs clockwise starting in the lower right-hand quadrant. Shaded areas represent the region of the heliosphere dominated by slow solar wind (yellow), and the region accessible to space probes in the ecliptic (green)

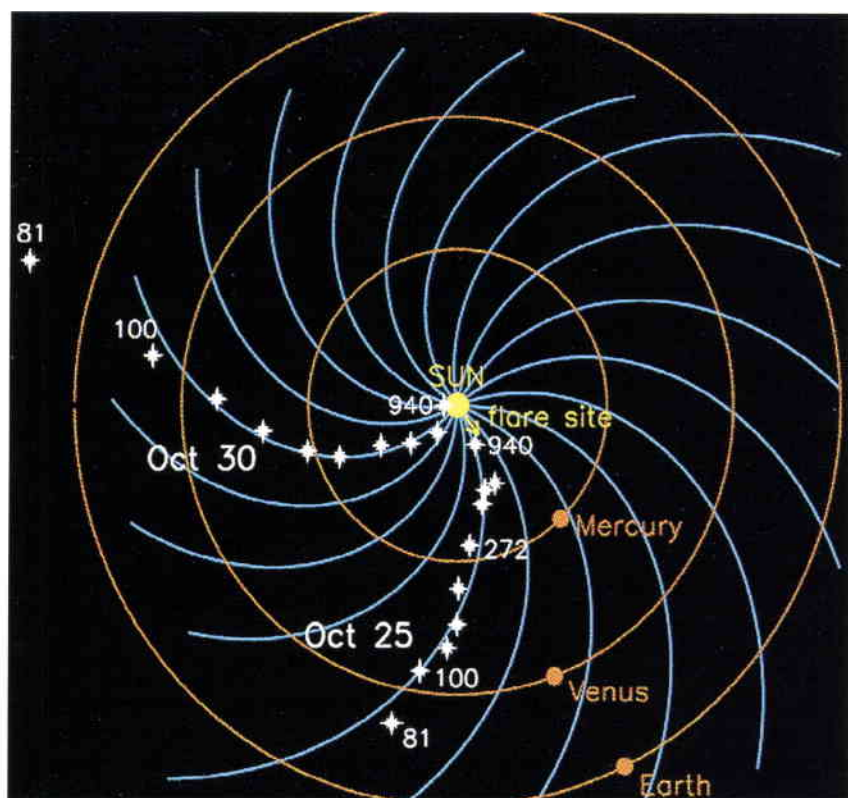


Figure 3. 'Snapshot' of the spiral shape of the interplanetary magnetic field, as obtained from radio observations from Ulysses. This view from the north ecliptic pole is based on Ulysses radio measurements made as it was passing over the Sun's south pole. The white symbols represent the actual observations of the location of outward-moving streams of electrons, ejected from the Sun on 25 and 30 October 1994. The numbers indicate the frequency of radio emission, so that '940' represents emission at a radio frequency of 940 kHz. A yellow arrow points out the location of the Sun where a solar flare on 25 October 1994 ejected the electrons tracked by Ulysses on that date. The spiral blue lines illustrate the shape of the magnetic field as predicted from theory for a constant solar wind speed (Courtesy of NASA/GSFC)

The north-south symmetry discussed earlier is associated with the heliospheric current sheet (HCS) that separates oppositely directed magnetic fields in the two hemispheres and defines the Sun's magnetic equator. The corresponding magnetic axis passes through the Sun's polar caps; it is the tilt of this axis relative to the Sun's rotation axis which causes alternating slow (low-latitude) and fast (high-latitude) solar-wind streams to sweep over an observer in the ecliptic. Because of the radial outflow of the solar wind, the fast streams eventually run into the slower wind ahead, forming so-called 'co-rotating interaction regions' (CIRs). These are regions of compressed solar-wind plasma, which, as the name suggests, co-rotate with the Sun. At distances beyond 1 AU, CIRs are often bounded by forward and reverse shock waves. As will become apparent, the investigation of CIRs themselves, and their influence on the energetic particles and cosmic rays that populate the heliosphere, forms a major theme in the scientific output of Ulysses.

Energetic particles and cosmic rays

Prior to Ulysses, it was known that the shocks associated with CIRs are able to accelerate low-energy charged particles. Characteristic increases in particle intensity are frequently observed when a CIR sweeps past a spacecraft once per solar rotation. At much higher energies, the same CIR can act as a temporary shield against incoming cosmic rays, causing the observed intensity to decrease rather abruptly, then slowly recover.

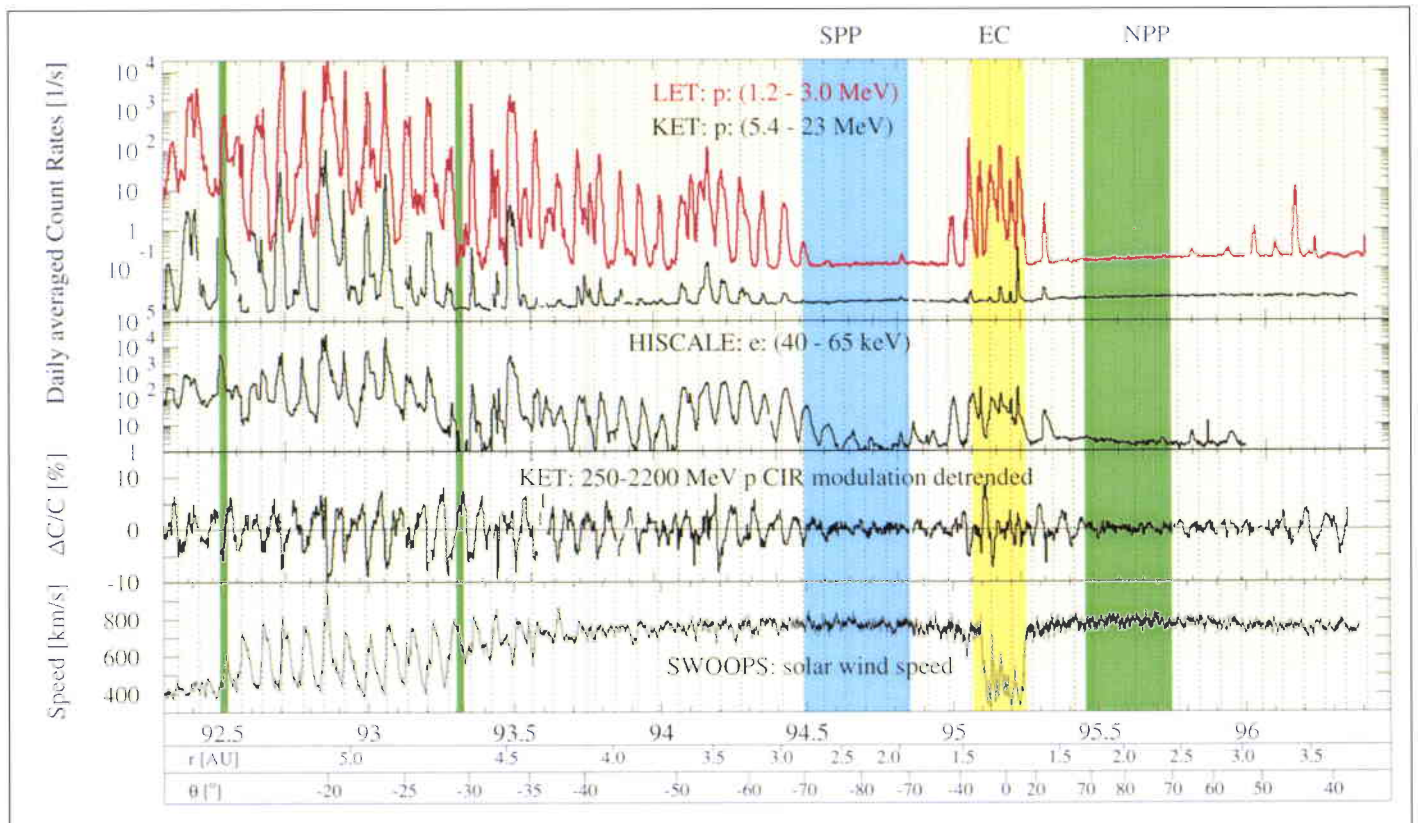
Surprisingly, Ulysses discovered that the recurrent effects in energetic-particle and cosmic-ray intensity extend to much higher latitudes than the CIRs themselves. Under the influence of the magnetic configuration of the Sun, the angle between the Sun's rotational and magnetic axes changes with the solar cycle. Near solar minimum, the magnetic and rotational axes are nearly aligned, so that the CIRs are restricted to relatively low heliographic latitudes (typically less than 30 degrees).

As shown in Figure 4, the series of recurrent increases and decreases starting at low latitudes clearly extends to regions far beyond the latitude range of the CIRs or their associated shocks. The Ulysses observations could be explained more easily than previously thought if the particles are able to move across the mean magnetic field to higher latitudes. An alternative explanation is that the differential rotation of photospheric foot points of heliospheric magnetic field lines interacts with the non-radial near-Sun expansion of the solar wind to produce field lines that deviate drastically from the traditional constant-latitude spirals (see Fig. 5). The result is to bring field lines from high latitudes near the Sun to low latitudes at 15 AU or more from the Sun, thereby connecting Ulysses to the acceleration region of the energetic particles. This remarkably different magnetic topology is not detectable near the ecliptic plane; it could only be discovered by observations at high heliolatitudes. If confirmed by further work, this theory, based exclusively on Ulysses data, will revolutionise our understanding of the heliospheric magnetic field and cosmic-ray transport.

A major goal of Ulysses was to investigate the physics of propagation of energetic particles in the heliosphere. In particular, the question was posed as to whether or not cosmic rays would have easier access to the inner heliosphere along relatively straight magnetic field lines expected over the poles of the Sun. Ulysses showed that the cosmic-ray intensity increased by less than a factor of two from the equator to the poles, implying nearly equal difficulty of access. A possible explanation is found in the Ulysses discovery that large-amplitude waves in the magnetic field, which obstruct cosmic-ray propagation, are a characteristic feature of the high-latitude fast solar wind.

Interstellar gas and pickup ions

Ulysses has, for the first time, observed a variety of atoms entering the heliosphere from interstellar space. With a new technique to directly detect low-energy (>30 eV) atomic



helium, the local angular distribution of He was measured and, from these observations, the velocity vector and kinetic temperature of the interstellar neutral helium at the boundary of the heliosphere have been determined with unprecedented precision. The velocity vector describes the motion of the Solar System through the surrounding Local Interstellar Cloud (LIC). Furthermore, from the neutral and pickup helium (see below) observed locally with Ulysses, it was possible for the first time to infer the neutral helium density in the LIC (0.0155 per cm^3).

Ulysses discovered a vast heliospheric population of ions (so-called 'pickup' ions) produced from interstellar atoms and dust grains by photo-ionisation and charge exchange with the solar wind. Measurements of these pickup ions (H, He, ^3He , ^4He , C, N, O and Ne) on Ulysses have led to important new results, including the following:

- the abundance of atomic N, O and Ne in the local interstellar cloud was established for the first time
- the discovery of C revealed new sources of neutral particles in the heliosphere.

Cosmic dust

The dust detector on the Ulysses spacecraft is the first to directly detect dust at high ecliptic latitudes. The primary pre-flight objective was to obtain new information on the latitude and radial distribution of interplanetary meteoroids. This objective included separating the

cometary and asteroidal populations from each other as well as measuring the beta-meteoroid population (meteoroids that are leaving the Solar System) which presumably originate via collisions from these two populations.

Other important objectives were to measure the flux of interstellar grains (if they existed in the Solar System), to measure dust in the Jovian magnetosphere as Ulysses flew by Jupiter, and to look for previously unknown dust populations. All of these pre-flight objectives have been accomplished, with the

Figure 4. Cosmic-ray and energetic-particle measurements made by the COSPIN experiment on Ulysses showing the recurrent pattern (26-day period) of low-energy increases and high-energy decreases in intensity persisting up to the highest latitudes. The corresponding solar-wind data show periodic effects only up to latitudes of ca. 35 degrees

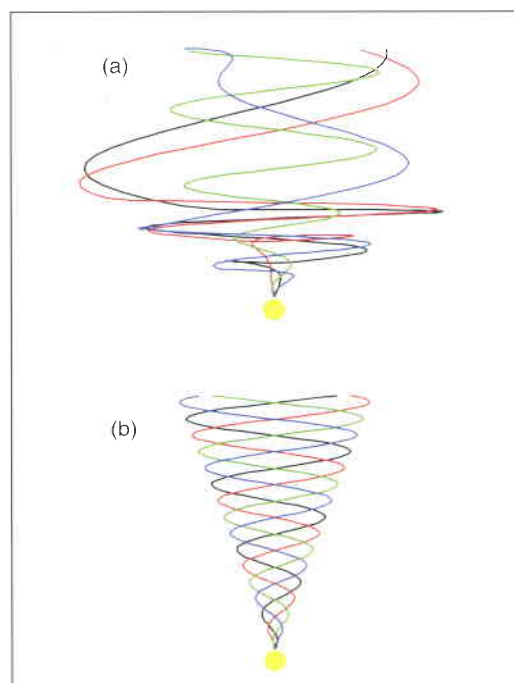


Figure 5. Ulysses magnetic-field measurements have caused theorists to revise their models of the heliospheric magnetic field. Shown here is the high-latitude field configuration proposed by L. Fisk (a), compared with the traditional Archimedes spiral model (b) due originally to E. Parker

exception of additional work to better determine the asteroidal versus cometary contributions to the zodiacal cloud. The Ulysses data, of course, suggest new problems to solve that were not anticipated before launch.

The dust experiment has discovered a flux of interstellar grains passing through the Solar System. The detections occur at the rate of about one detection every 3 or 4 days. **Streams**, or bursts, of dust were also discovered to be emanating from the Jovian system. An analysis of all Ulysses data has identified a total of 11 such streams, and revealed that the dust grains are electrically charged and their trajectories are bent by the solar-wind magnetic field.

Astrophysics

The study of the Sun and its environment by Ulysses has an obvious importance to stellar astrophysics, providing the only possible detailed analysis of the interaction of a typical star with its surroundings. Ulysses has also made important contributions to astrophysical studies that reach far beyond the heliosphere.

For example, the gamma-ray burst (GRB) experiment provides a distant point in space to obtain arcminute positions for cosmic gamma-ray bursts and to observe solar-flare X-radiation stereoscopically. It has become the flagship in the 3rd Interplanetary Network of gamma-ray burst detectors. This network includes, or has included, Pioneer Venus Orbiter, the Russian GRANAT spacecraft, WIND, Yohkoh, the Compton Gamma-Ray Observatory, and the Italian SAX mission, among others. The synergy which exists among these missions, as well as the German ROSAT and Japanese ASCA X-ray observatories, has permitted identification of a possible quiescent X-ray counterpart to a gamma-ray burst source and determination of the position of a recent GRB to 0.76 square arcminutes. The latter observation has led to the first possible detection of an optical counterpart to a gamma-ray burst source.

Ulysses has also carried out cosmic-ray studies significant for astrophysics. So far, the measurements have provided isotopic abundance measurements of unequalled precision for many of the more abundant elements in the cosmic radiation, including the first fully-resolved, good-statistics measurements of the isotopes of iron and nickel which have already eliminated some models for heavy-element nucleosynthesis and for the origin of cosmic rays. However, the quality of the measurements for many species is still

limited by statistics; continued collection of events is required not only for the refinement of the isotopic composition of the more abundant elements already measured, but also to permit measurements of less-abundant elements such as Cl and Ar which have important implications for nucleosynthesis and propagation theory.

The Ulysses measurements of the ratio of helium isotopes ($^3\text{He}/^4\text{He}$) in the local interstellar gas, the first of their kind, have made it possible to compare present-day light-element abundances in the Local Interstellar Cloud with their values at the time of the formation of the Solar System. The abundances were found to have remained essentially unchanged, placing new constraints on models of galactic chemical evolution. These data have also led to important refinements in another fundamental cosmological parameter, providing information on conditions that prevailed in the Big Bang.

Anticipated results from the Ulysses mission at solar maximum

The mission of Ulysses is to explore and define the heliosphere in three dimensions. For the solar-minimum heliosphere, as detailed above, this mission has been accomplished, changing our view of the heliosphere and stimulating a wide variety of theoretical and modelling efforts. Since the heliosphere is a dynamic structure which undergoes large variations in both large- and fine-scale structure over the period of a solar magnetic cycle (22 years), it is critical that observations also be obtained near solar maximum. This will be accomplished during Ulysses' second solar orbit (Fig. 6), the so-called 'Ulysses Solar Maximum Mission'. It is certain that new insights will be gained as we continue to observe the effects of increasing solar activity, changing coronal structure and, ultimately, the reversal of the solar magnetic polarity from the vantage point of Ulysses at high latitude in the coming solar maximum.

In addition to heliospheric studies, Ulysses' role in astrophysical investigations will continue to yield rewards during the Solar Maximum Mission. Ulysses' discoveries of matter from the local interstellar cloud and identification of vast regions of neutral matter in the inner heliosphere are giving us a new view of the phenomena and conditions beyond our Solar System; a view which will become much better defined through continuing observations. The determination of accurate locations for gamma-ray bursts will continue through the second orbit, and the continued collection and identification of rare nuclear species from the galactic cosmic radiation will increase the

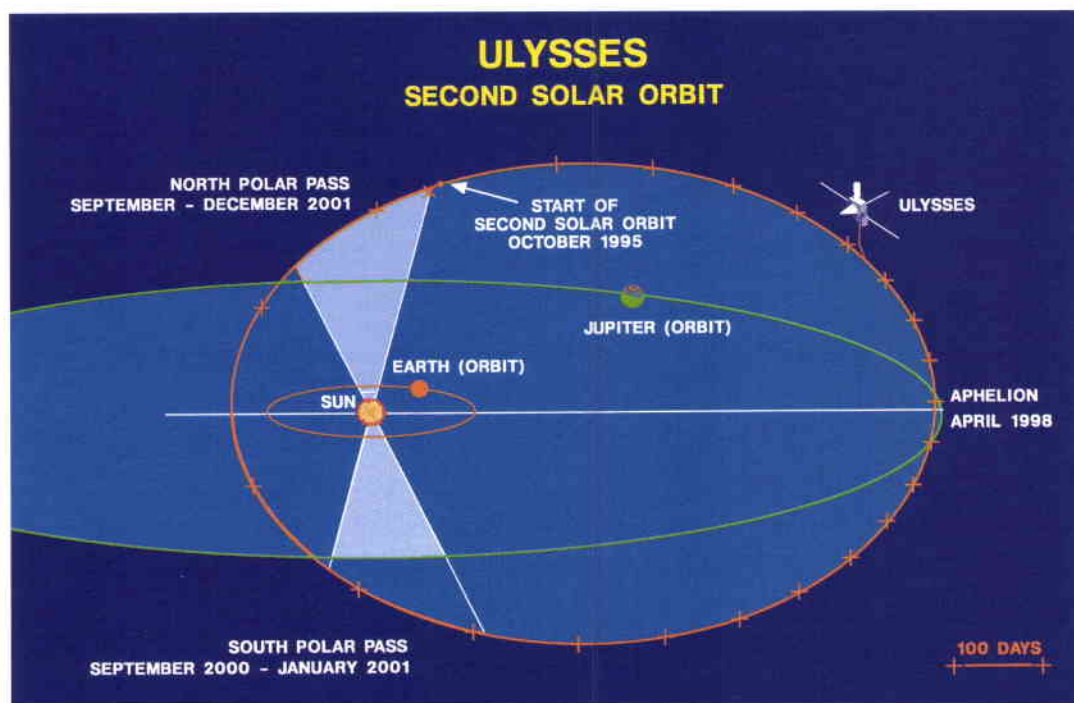


Figure 6. The Ulysses orbit, showing the second set of polar passes in 2000/2001. The spacecraft is currently close to aphelion at a distance of 5.3 AU from the Sun

accuracy with which we know the composition of the only sample of matter available for analysis that has probed conditions in large regions of space outside the Solar System in the Galaxy.

Many of the topics of the Ulysses Solar Maximum Mission can only be addressed fully when Ulysses revisits the polar regions in 2000-2001. Nonetheless, observations in the intervening period, i.e. 1998-99, are critical to placing the later observations in context. Furthermore, we do not know when many of the processes related to the onset of solar maximum will begin to appear at the location of Ulysses.

Key topics for the next phase of the Ulysses Mission include:

- The sources of fast and slow solar wind at solar maximum.
- Variations in solar-wind composition and coronal density and temperature with the solar cycle.
- Consequences of the change in polarity of the solar magnetic field.
- The evolution of the heliospheric current sheet(s) in three dimensions.
- The study of high-latitude CMEs and other transients, rarely seen at solar minimum.
- The investigation of giant flares.
- The study of solar energetic-particle events in three dimensions.
- The evolution of cosmic-ray gradients and the consequences of the change in magnetic polarity.
- The study of CIRs and modulation of cosmic rays in three dimensions.
- The dependence of the interstellar dust flux

and direction on the phase of the solar cycle.

- Improvements to the measurement of neutral interstellar gas parameters.
- Improved statistics for interstellar pickup ions and $^3\text{He}/^4\text{He}$ ratio measurements.
- The isotopic abundances of the cosmic radiation.
- Further studies of gamma-ray bursts and their optical counterparts.

Achieving these goals will involve collaborations with many other spacecraft and ground-based projects, but the unique high-latitude perspective of Ulysses and its integrated instrument payload are invaluable assets.

For most of the questions described above, the Ulysses Solar Maximum Mission represents the only opportunity in our lifetimes to provide robust answers. The capability to contrast the observations from solar minimum and solar maximum is crucial to placing the data in perspective. It is certain that the additional data obtained during the rise to and at solar maximum, in combination with the earlier Ulysses data, will more than double our understanding of the three-dimensional heliosphere. The goals relating to the interstellar medium, as well as the astrophysical objectives, also represent opportunities that may never be repeated.



Validating Future Operational Communications Techniques: The ATM Testbed

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Introduction

In its preparation of a ground infrastructure to support the future operation of the Columbus Orbital Facility (COF) and the Automated Transfer Vehicle (ATV), ESA has already defined a communications network that will exploit the benefits of Asynchronous Transfer Mode (ATM). To validate the applicability of ATM

ESA's spacecraft and payload operations support networks are facing rapidly increasing demands for network bandwidth, induced by the requirements for the Columbus Orbital Facility and by Earth-observation projects like Envisat. The traditional implementation of operational networks is based on technologies that are adequate for lower data rates, but which become very expensive when rates of tens of megabits per second have to be supported. Since the traditional technologies permanently reserve the bandwidth of the maximum data rate of bursty traffic, these resources generate costs even during trafficless intervals. The new Asynchronous Transfer Mode (ATM) technology has the potential to respond to such shortcomings in today's systems and to meet tomorrow's communications requirements in a very cost-efficient way.

technology for meeting the various service requirements, ESOC, in cooperation with Deutsche Telekom, has set up an ATM Testbed, which in the initial phase will serve to prove the concept. After the implementation of the operational networks, this Testbed will support simulations, trouble-shooting, and compatibility testing for new equipment before it is moved to the operational network. The ATM Testbed has been integrated into an existing communications reference facility which has already been used as a prototype implementation in supporting telescience missions with Spacelab and the Mir space station.

The advantages of ATM communications

Today, the telephone network has become our most efficient communications tool because it combines global availability, short response time, and user friendliness. Consequently, the

newer services like digital facsimile still exploit the telephone infrastructure. However, as the analogue telephone network was not designed to support these digital services, other dedicated public and private data networks have been set up. Each of these networks has needed its own resources. As a result, the equipment involved has been too specialised for each service to make efficient use of the spare resources of another network.

Nowadays, new communication services are appearing, with sometimes as yet unknown exact requirements. Examples are video conferencing, high-speed data transfer, videophones, video broadcasting, and home learning (tele-education).

In order to support old, new, and future (unspecified) services in a unified manner, a Broadband Integrated Services Digital Network (B-ISDN) has been envisaged. As only one common network needs to be designed, the overall costs of design, installation, operation, and maintenance should be reduced. ATM has been chosen as the transmission mode for this integrated network. This technology is connection-oriented, switched (like the telephone network, where there is a process of 'call setup' and a line connects the two telephone sets for the duration of the conversation), and multiplexed (like the data networks, allowing capacity sharing between different users and applications). The circuit set up for the duration of a call is therefore virtual, rather than real.

ATM has been designed to be service-independent, thereby allowing the integration of voice, data, image, video, and multimedia traffic over the same network. Such a network will be flexible enough to adapt itself to new needs and anticipated services. When establishing a connection, the user is allowed to specify an 'expected category of service'.

The five ATM service categories represent new service building-blocks that make it possible for users to select specific combinations of traffic and performance parameters (Quality of Service, or QoS), thereby providing a much greater degree of flexibility and fairness in the network's utilisation. Figure 1 shows how these service categories, which are briefly described below, share the capacity of a link:

- The Constant Bit Rate (CBR) service category is used by connections that require a static amount of bandwidth to be continuously available throughout the connection time. The user specifies the Peak Cell Rate (PCR) needed. This category can be used by any application for which the end system's response-time requirements justify occupying a fully reserved channel (normally synchronous services like interactive audio or video).
- The non-real-time Variable Bit Rate (VBR) and real-time VBR service categories are best used by sources with a 'bursty' behaviour (i.e. the sources transmit at a rate that varies with time). Apart from the PCR, other traffic parameters are the Sustainable Cell Rate (SCR) and the maximum burst size (MBS). The main difference between these two categories resides in the timing requirements. Real-time VBR can be used by native ATM voice with bandwidth compression and silence suppression. Non-real-time VBR can be used for data transfer in response-time-critical transactions (like satellite monitoring and control) and for frame-relay inter-working.
- The Unspecified Bit Rate (UBR) service does

not specify traffic-related guarantees. The network does not make any kind of commitment regarding the service that the user will get - it is a best-effort service. Typical applications are computer communications applications like file transfer and electronic mail (e-mail).

- The Available Bit Rate (ABR) service includes a feedback control that allows the characteristics of the connection to be changed during its lifetime. The user specifies the maximum required bandwidth (PCR) along with a minimum usable bandwidth (Minimum Cell Rate, MCR). The network will inform the user about any variation in the available bandwidth, which will never become less than the minimum agreed. This category provides an economical support service to those applications that have relaxed requirements on timely delivery for throughput and delay. It gives the carriers a chance to sell their excess - and otherwise unused - capacity. An example of such an application is the interconnection of Local Area Networks (LANs).

For example, two-way voice communications have tightly constrained delay requirements, so that a CBR service is required. On the other hand, for an overnight data-distribution service, delay is not a key issue, and the capacity of the network can be used on an availability basis; the ABR service would be used in this case.

In this way, customers can choose to access the network how and when they actually need

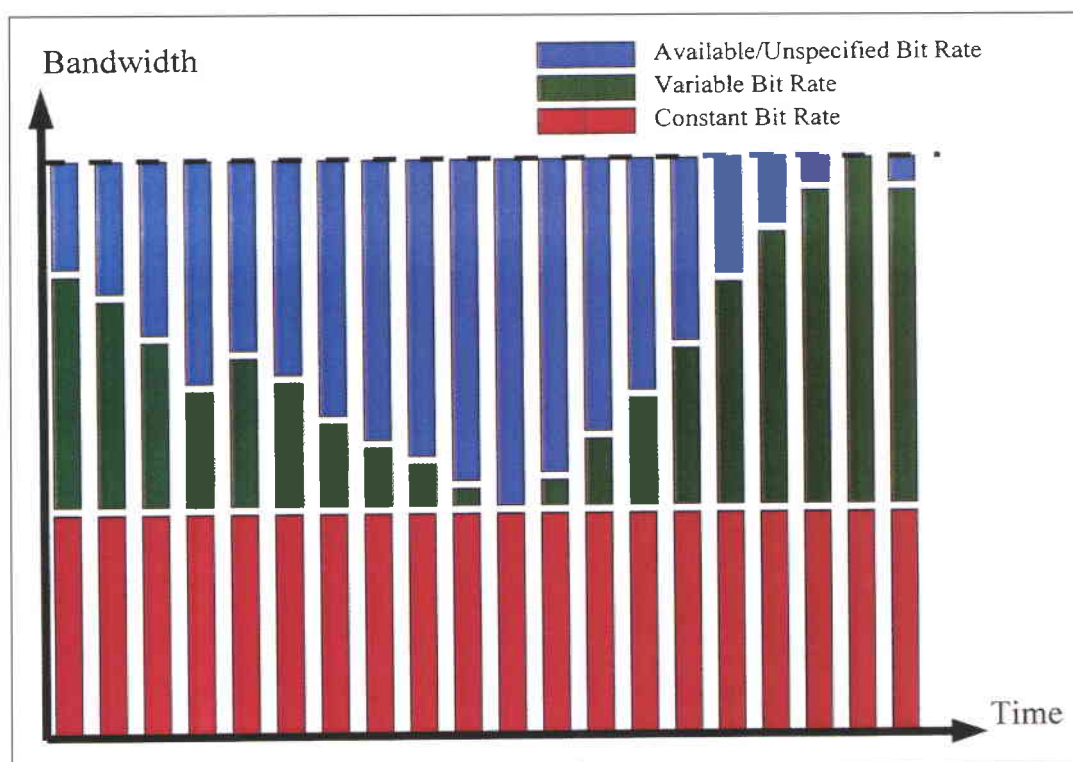


Figure 1. Qualitative overview of link usage by different service categories

it, while still maintaining their specific efficiency and quality requirements. Network operators can achieve maximum use of the deployed resources by sharing them between all customers and fulfilling the different user needs in a cost-effective way. The customer expects to profit from appropriate tariff strategies (e.g. the use of spare network bandwidth on an as-available basis should be priced considerably lower than the use of guaranteed bandwidth).

ESA's ATM target scenarios

One of the candidates for an ATM-based implementation is the network to support COF and ATV operations (Fig. 2). Known as the Interconnection Ground Subnetwork (IGS), it will connect all European sites to NASA in the USA, RSA in Russia, and the NASDA network in Japan, for remote operations and scientific-payload support.

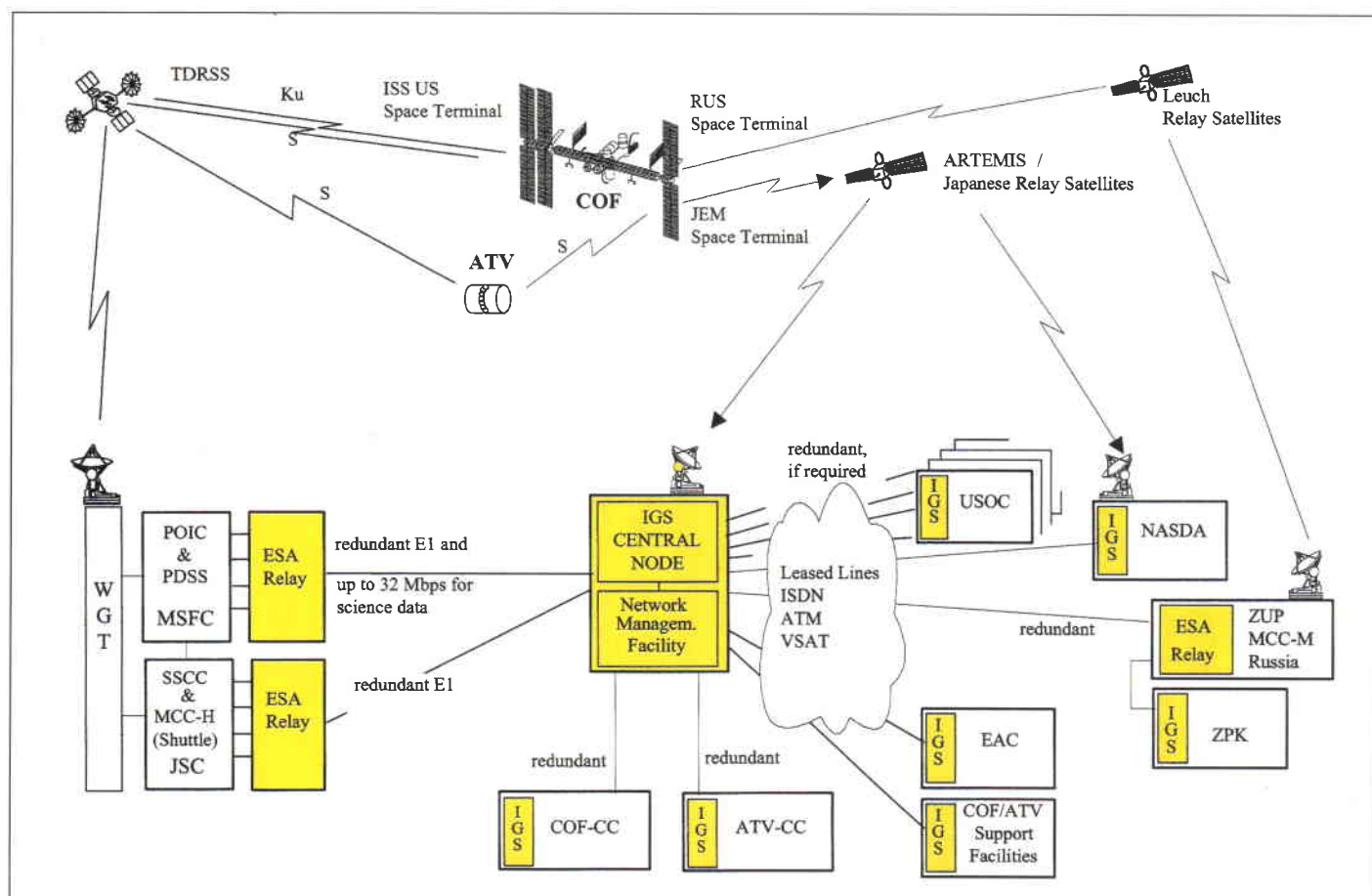
The primary inter-orbit link between the COF module of the International Space Station (ISS) and the COF ground segment is provided via NASA's TDRSS satellite relay system, and that on the ground via the corresponding NASA facilities at Johnson Space Center (JSC) in Houston and Marshall Spaceflight Center (MSFC) in Huntsville on the American side and ESOC on the European side. A second path between the COF module, via the Japanese Experiment Module (JEM) and the European

(Artemis) and Japanese data-relay satellites to European and Japanese ground facilities is being investigated as an option.

The main facilities within the ESA Member States are the control facilities for COF and ATV, the ESA Astronauts Centre (EAC), the User Support and Operations Centres (USOCs), and the engineering support facilities for COF and ATV. ATM-based nodes will be installed at all sites that communicate via the IGS. A node typically consists of one or two 19-inch racks which accommodate the communications equipment. The network is operated centrally from a dedicated Network Management Facility (NMF) located at ESOC. All elements of the network, including the nodes at the most distant sites, are remotely monitored and configured by the operator at ESOC utilising the dedicated NMF capabilities.

The IGS is required to support a broad spectrum of communication services, ranging from typical data-distribution services for telemetry, telecommanding and mission management information services, to new high-speed data applications for science, multimedia applications like video conferencing and multicasting, and voice conferencing for operations co-ordination. For experiment operations, a significantly large bandwidth and possibly highly bursty traffic will

Figure 2. COF and ATV target scenario, including the optional JEM link



have to be supported, with data rates up to 32 Mbit/s. In addition, the high-rate data flow for experiments is unidirectional from MSFC to ESOC and from there to the scientific users. Compared with this data flow, the bandwidth requirements in the reverse direction are rather modest. This type of traffic can be mapped perfectly into an ATM implementation, taking advantage of potential network cost savings for this type of traffic profile. In ATM, asymmetric and bursty traffic allows efficient sharing of link resources with other users. While the traditional technologies charge for permanent, bi-directional, symmetrically available bandwidth, with ATM the data transport service should ideally be charged according to the data volume transported. In practice, this is not quite attainable as, for example, requirements for real-time data services may impose less economical service conditions.

Other new projects like Envisat also have very similar communications requirements in terms of data volume and asymmetric traffic flow, where ATM again offers the most cost-effective solution. As explained above, ATM services are characterised by a variety of QoS classes with different tariffs. The choice is driven by the requirements in terms of reliability, data quality, delay tolerance and priority. As the mapping of requirements to service implementations is performance- and cost-sensitive and the carrier providers (telecom operators) are reluctant to provide pricing and performance prognoses for the years 2000 and beyond, the ATM Testbed provides an efficient platform with which to gain the necessary technical experience.

ESOC's ATM Testbed

ESOC's ATM Testbed is one element of a larger communications reference facility, which evaluates networking and communication techniques for ESA projects before they are actually proposed as implementation solutions.

There is a major trend in the implementation of ground segments for ESA projects to build on commercial off-the-shelf (COTS) equipment and services. This approach has also been followed in the field of networking, i.e. data transport between the relevant sites involved in mission operations, for many years. For communication systems located at ground stations, control centres and other facilities involved in mission operations, this trend is still evolving. This means that COTS products are used wherever possible and enhanced as necessary with custom developments to meet the requirements of individual missions.

The communications reference facility serves

as a test environment, into which technical solutions based on COTS products and services are integrated and then tested for their suitability to meet specific mission requirements in terms of functionality, bandwidth guarantees and availability (fail-safe scenarios). An important aspect of the test environment is that it is used to verify not only integrated products, but also the services being offered by international telecommunications operators. In the real-life implementation for each mission, the overall system ultimately relies on international communications services, e.g. traditional leased lines, Integrated Services Digital Network (ISDN), Frame Relay Virtual Private Network (VPN) service, ATM and Very Small Aperture Terminal (VSAT) based services. It is therefore crucial, particularly for new services like Frame Relay, ATM or VSAT, to validate technical interfaces and service performances in close cooperation with the carriers providing these services on an international basis.

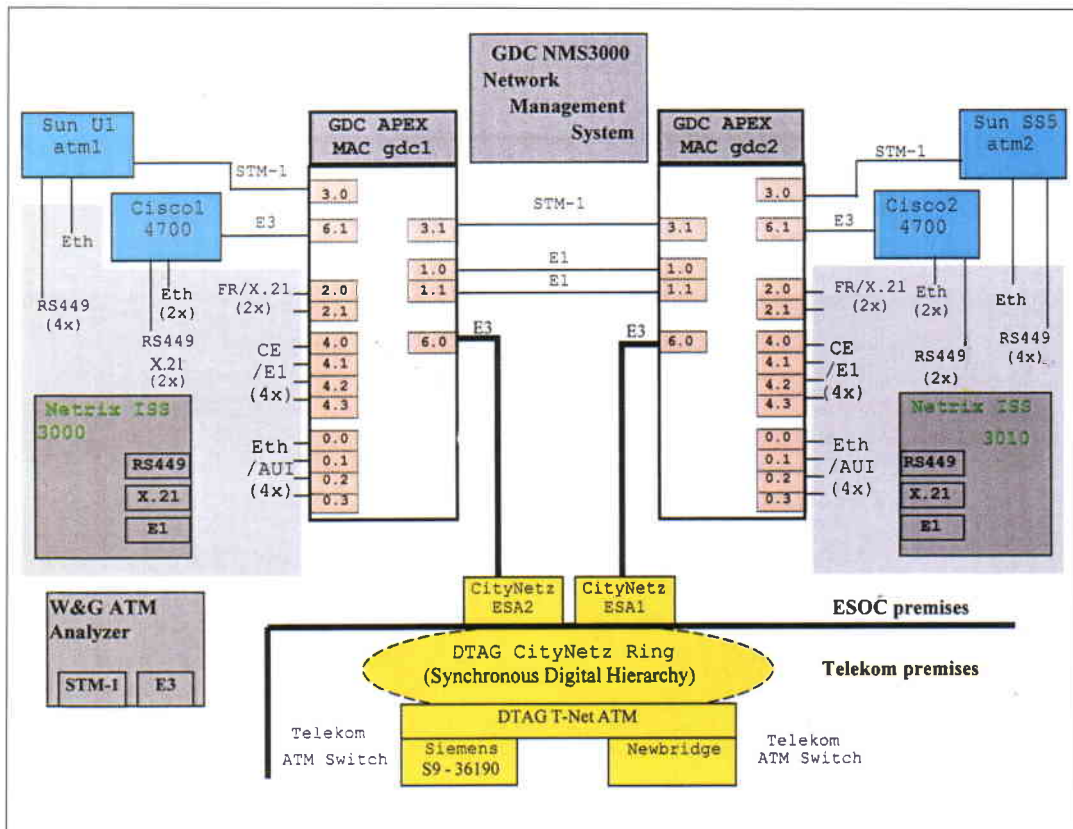
The ultimate goal of the communications reference facility is to validate technical solutions that meet ESA's project requirements in terms of both performance and cost, and which can be implemented within a well-defined schedule, thereby enabling a surprise-free implementation approach.

Since ATM-based services are well suited for high-rate data transport, high rate being defined here as above 2 Mbit/s, and delivery of high volumes of data, high volume being defined as more than 10 Gigabytes per day, special attention is being devoted to emerging ATM technologies and services. Hence the need for the ATM Testbed (Fig. 3), which has three main elements: equipment related to the ATM services and the private network, the access to the public ATM infrastructure, and the legacy services and applications which need to be integrated.

The two ATM switches are access concentrators and allow for the integration of all of the legacy services (shown in the shaded area) within the ATM network. They are linked together through different transmission media to create a private ATM network. The work stations and the routers act as native ATM users of these network on their ATM interfaces. From both switches public-carrier access is available, allowing the testing of interoperability and of the re-routing recovery mechanisms in the case of a (simulated) failure in the private network.

The shaded area corresponds to the existing legacy services – both data and circuit services

Figure 3. ATM Testbed configuration



– which should be integrated within the ATM network. For the data services, Frame Relay and Ethernet interfaces are available. For circuit services, like videoconferencing, voice, and data, over the existing (proprietary) switching system, the Circuit Emulation service is the most suitable.

Figure 4. The ATM internetwork analyser



An ATM network analyser makes it possible to monitor the data traffic and performance and to take measurements within the network. With a de-facto standard user interface, the analyser allows different parameters to be measured during the course of the tests. Figure 4 shows a snapshot of the analyser. The screen displays a Traffic Simulation tool, which allows one to inject up to three different kinds of traffic into the ATM network. Each traffic source can be modelled using mathematical statistical distributions.

The validation concept

The validation concept used in the ATM Testbed follows the principle of local testing as much as possible without interfacing to carrier services, in order to minimise the costs involved. The two ATM nodes are therefore first connected back-to-back in a local setup by a variety of emulated leased lines (E1: 2Mbit/s, E3: 34 Mbit/s, and STM-1: 155 Mbit/s). In this configuration, all ATM services provided in the current software version of the node are verified. Individual tests always involve end systems and/or special test equipment that allow the generation of data in the required manner to stress the nodes, e.g. to allow for the occurrence of congestion in the switches in order to observe their exact behaviour. This is illustrated in Figure 5. The middle rack carries two pieces of switching equipment, with the routers below and the work station with the management software in the front part. The analyser is used to inject the traffic into the

network to stress and observe the behaviour of the switches.

Only after the satisfactory completion of these first tests are the nodes connected via a national public ATM network (T-Net ATM from Deutsche Telekom). In this configuration all ATM services provided by the national network are verified for interoperability with the private ATM equipment. These tests provide a first indication of what can be reliably achieved in a real networking scenario that involves only one carrier.

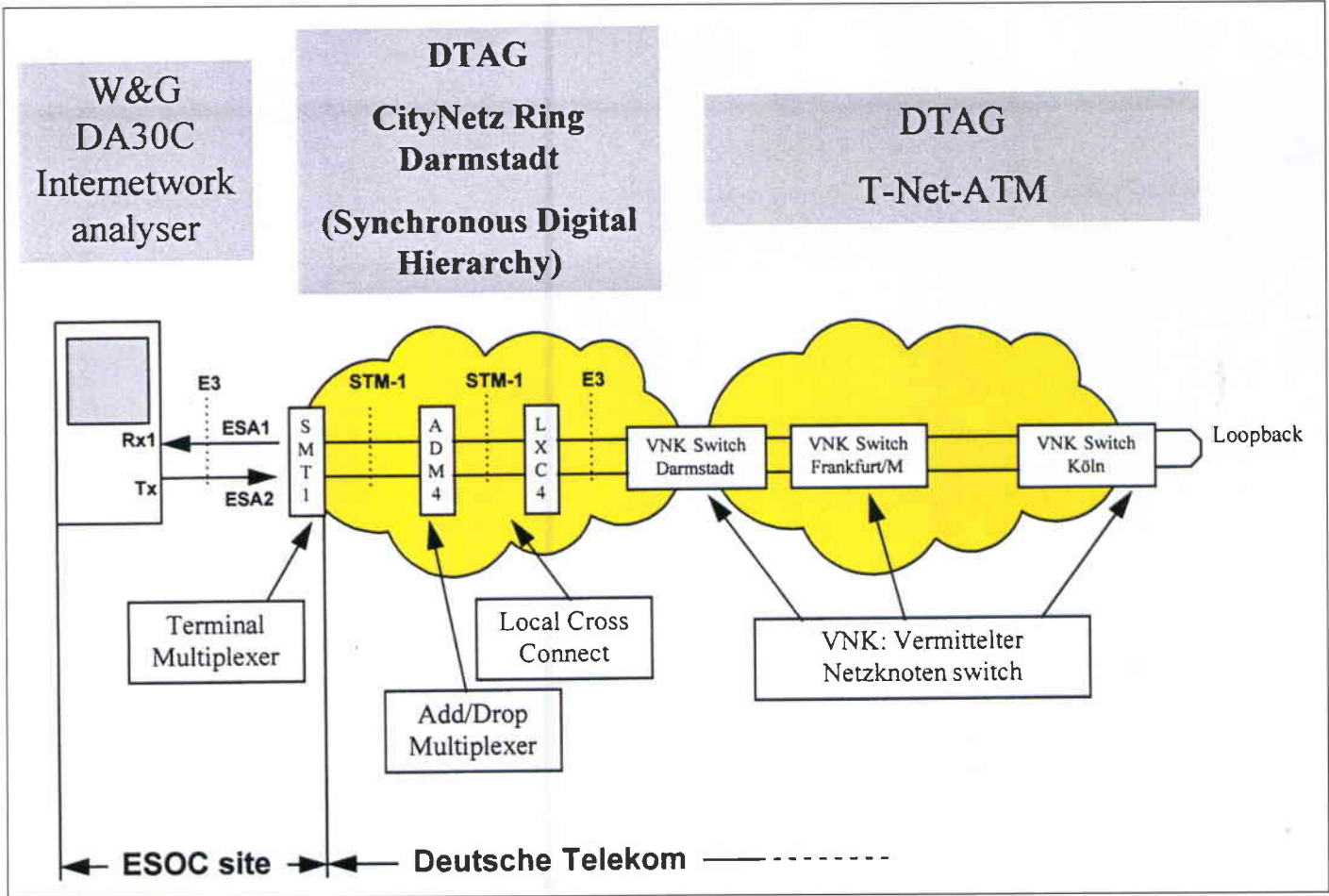
Figure 6 is an example of such a test. The network analyser is connected to the access port of the public network, and a loop-back is performed in a far-end ATM switch in Cologne (Germany), shown on the right, to measure the performances over the different interfaces.

When this set of tests has been performed satisfactorily (with the limitations observed), the nodes are internationally linked via interconnected carrier ATM networks. In this configuration, all ATM services provided by the carriers involved are verified for their interoperability with the private equipment. Results of these tests in general show further limitations in terms of available ATM services and constraints on their usage due to the



Figure 5. The ATM test setup at ESOC

Figure 6. Test via the ATM network of Deutsche Telekom



interoperation of different carrier networks. These tests give a first indication of what can be reliably achieved in a real networking scenario that involves multiple carriers. Such a scenario has to be very close to the implementation options which have to be considered for ESA missions.

Future envisaged test scenarios could be the transport of high data volumes from Kiruna in Sweden to ESOC in Germany and to ESRIN in Italy for Earth-observation missions, and the connectivity from MSFC (USA) to ESOC in preparation for providing the communications support for the COF.

ATM tariffs and expected savings

The tariff structures of ATM networks distinguish one-time installation charges, regular monthly charges and variable-usage charges. The one-time charge is for the installation of the service. The monthly service charges are based on the access circuit speed and the distance to the next ATM cross-connect switch. This is typically a leased line between an ATM user site and the next ATM node of the telecommunications network provider. The variable-usage charges within the ATM network are composed of the connection charges based on requested bandwidth, connect time of day, connection duration, connection distance or traffic-volume-dependent charges.

ESA's future spacecraft and payload operations will require substantial data transfers between receiving ground stations, ESA sites, the sites of other space agencies, and the user sites (control centres, science user sites, etc.). The operations concept distinguishes on-line telemetry and telecommand services for time-critical real-time monitoring and control, and offline telemetry services for non-time-critical measurement data. The bulk of the data is not time-critical.

Therefore a potential utilisation scenario could be such that the crucial time-critical online services, which are only used during satellite connect times (passes over ground stations), will be supported by appropriate variable bit-rate services. The less time-critical offline services could be supported by available bit-rate services, making most efficient use of available excess capacity in the carrier network. In a private-network implementation, these types of services would be supported over the same physical links. For the critical variable-bit-rate services, the traffic contract would specify the sustainable cell rate, while for the less time-critical available bit-rate services the traffic contract would specify a minimum cell rate. In

other words, the communication system would automatically distinguish between the two types of traffic, where the bulk data applications would always be treated as background tasks making use of the available excess capacity in the network without requiring special network-management intervention.

With such a utilisation concept, ESA can profit substantially from the forthcoming network services and their different tariffs. This holds true for the case where ESA makes use of commercial services, but also for the case where ESA is the network operator (private network approach). In the latter case, the new network services will lead to higher network utilisation, due to dynamic bandwidth sharing with guaranteed throughput for the critical online applications.

Conclusion

Telecommunications technology is changing at an unprecedented rate. Since a newly emerging technology like ATM lacks a proven performance record under real operational conditions, the establishment of a testbed infrastructure is a mandatory step in order to minimise the risk inherent in its introduction into a mission operations environment and to demonstrate its overall viability.

Such an approach also has other inherent advantages. Space projects can be made aware of the benefits of this communications technology, especially the cost-saving that it brings for the transfer of large volumes of data to the scientific user community. Distributed data applications, normally developed by other engineering teams, can be designed to take into account this network technology, and their interoperability can already be validated with the testbed infrastructure during the design phase. The complexity of the network configuration and operations can be assessed, and personnel can be trained well in advance of the operational phase.

Finally, the testbed experience provides the means to be better prepared for providing realistic implementation plans for ESA's future space projects, and for benefitting to the maximum possible extent from the availability of the latest ATM services.

Acknowledgement

The authors gratefully acknowledge the continuous support that they have received from the ESA Directorate of Manned Space Flight and Microgravity, which made much of the work reported here possible.

An Overview of Structural Acoustics and Related High-Frequency-Vibration Activities

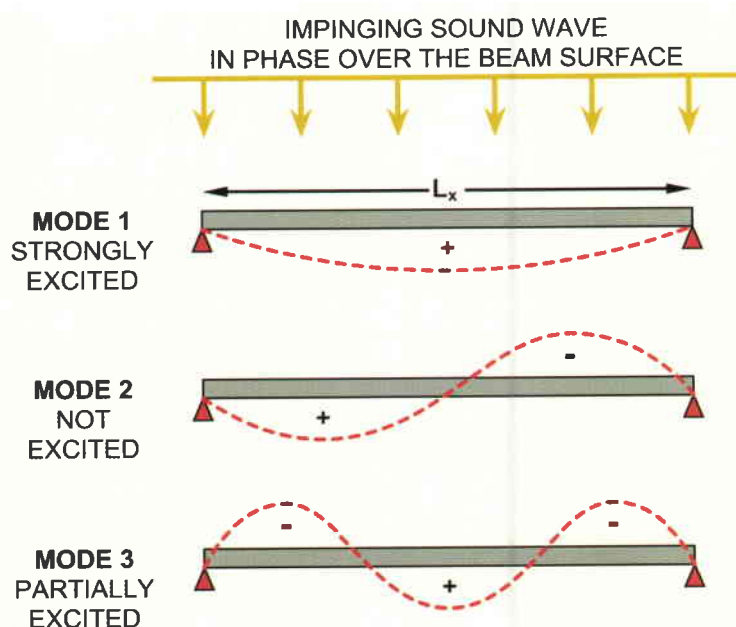
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Acoustically excited structures

The only difference between mechanical and acoustical excitation of a given structure, with its own particular modal characteristics, is the actual coupling mechanism between these structural modes and the excitation field being applied. In the case of a structure on a mechanical exciter table, the coupling efficiency depends on the forces at the table/structure interface plane. In the case of acoustic excitation, the coupling efficiency depends on how well the sound waves interact with the structural modes.

This article describes several of the more typical structural acoustic and high-frequency-vibration problems that can severely adversely affect spacecraft structures and their payloads. It attempts to provide instructive background for the nonspecialist and describes the key tools that have been developed by the Agency - including the ESA Structural Acoustics Design Manual (ESA PSS-03-204) - to combat such problems, as well as some of the practical experience that has been acquired through laboratory testing. Application of some of these tools for in-orbit spacecraft health monitoring is also addressed.



A simple example of acoustic excitation is provided by a beam subjected to an incident sound field (Fig. 1). Considering the lowest-order half-wave structural mode, if the sound is in phase over the structural surface strong coupling occurs. However, in the case of the second-order mode, the energy contents of the vibrating half-waves would 'cancel each other out', so that the mode would not be excited at all. This coupling efficiency is referred to as the 'joint acceptance' and corresponds to the modal participation factor or effective mass found in mechanical vibration synthesis.

An example of reverberant room excitation is given for odd-numbered modes in Figure 2. A number of features that apply to many plate-like structures are in evidence here. The beam is most strongly excited for all modes when the half-wave ($\lambda/2$) is greater than the beam length, but the coupling efficiency drops rapidly with mode number. When $\lambda/2$ is much smaller than the mode size, the 'joint acceptance' is essentially the same, irrespective of structural mode number. A further important aspect is that the lowest-order modes are likely to be efficiently excited whether the sound field is reverberant or directional. This is because the sound pressures are likely to be 'in phase' over the structural surface. Furthermore, a plate in a reverberant sound field will exhibit orthogonal 'joint acceptance' beam properties.

A broad conclusion from the above is that for many classes of structures exhibiting a plate-like vibration behaviour, such as antennas and solar panels, their low-order mode response is likely to be of greatest importance and may well be restricted to one mode. Prediction of their susceptibility to noise-induced damage can often be based on this simplifying assumption. Where the predominant acoustically excited and static modes are similar, assessment of combined acoustical and quasi-static loads is also greatly eased.

Figure 1. Excitation of a simply supported beam by a normal-incidence sound wave

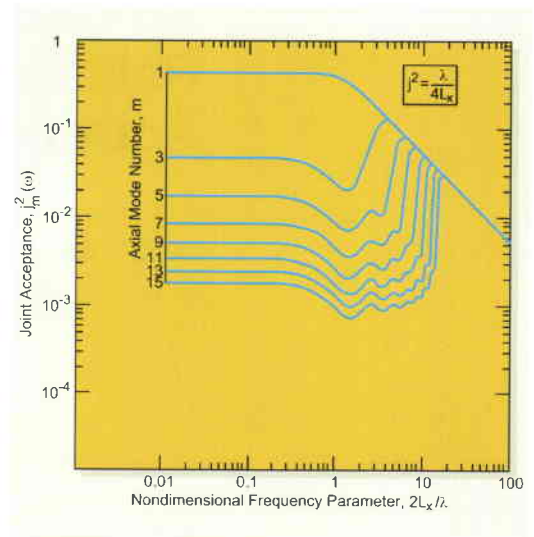
Figure 2. Joint acceptance properties indicate the coupling efficiency between the sound field and the structure. In most situations, for beams and plate structures efficient coupling occurs when the length of the structure is smaller than the half sound wavelength. It falls rapidly with mode number. At high frequencies, the coupling efficiency is largely independent of structural mode number at a given frequency

Wider frequency range problems

Of course, by no means all noise-excited configurations can be dealt with using single-mode approaches. For example, the responses of platform-mounted equipment may be largely due to the mechanical transmission from the acoustically excited supporting honeycomb panel. The response of the equipment's internal items such as a printed-circuit board will depend on its own resonant modes and the mechanically transmitted vibratory power flowing from the panel. In the case of microvibrations, the energy is transported from, say, a reaction wheel, around the spacecraft structure, via various mechanical transmission paths, into the jitter-sensitive equipment item. Statistical Energy Analysis (SEA) provides a means of assessing the average plateau of such vibrations and the importance of the routes through which any vibratory power may be transmitted from a remote part of the spacecraft.

Whilst analysis of the detailed behaviour of individual modes is possible using finite-element and classical methods, this becomes impractical and usually not warranted when considering a wide frequency range and the impact of very many modes, as experienced in this class of structural acoustic problem. SEA can be used when the number of acoustic and structural modal resonances in a given frequency band (their modal density) is sufficiently high. It is then possible to consider the average power flow between different subsystems (e.g. the chamber reverberant sound field, the platform, a central cylinder and its acoustic cavity, the equipment item, etc.) and evolve a statistical assessment of their time-averaged response behaviours in both space and time. An example is given in Figure 3.

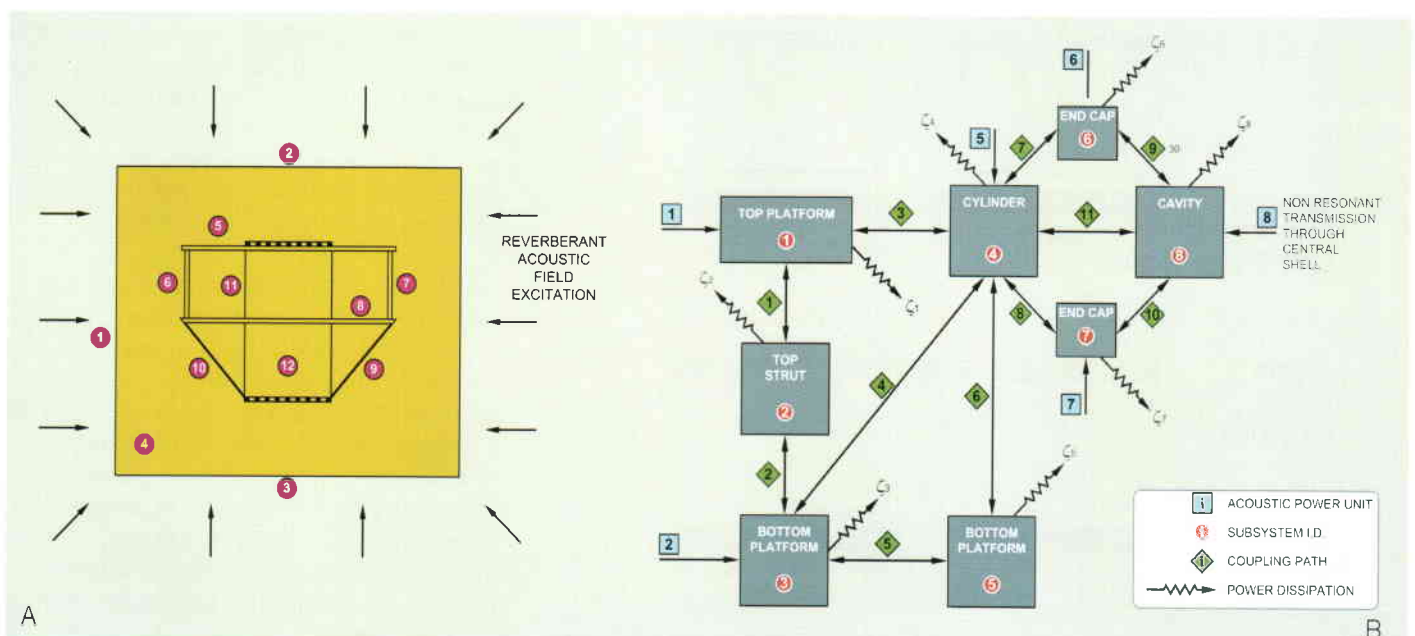
Figure 3. Statistical Energy Analysis (SEA) can be used to investigate the flow of vibratory energy between different parts of the spacecraft, due either to acoustic excitation or localised mechanical vibration



Some findings from acoustic tests in the LEAF

Commissioning studies using a range of old test structures and payload elements (Fig. 4) produced findings which were subsequently confirmed and extended by assessments made during the Ariane-5 fairing acoustic test campaign performed in the new Large European Acoustic Facility (LEAF) at ESTEC in Noordwijk (NL). Sound-pressure levels representative of the lift-off environment were reproduced. The Olympus structural model was first installed inside the Ariane-5 fairing and used to investigate the combined fairing/payload acoustic response with both an air- and a helium-filled fairing. Then Olympus was placed in the chamber alone and exposed to the sound field (Fig. 5).

It has been established that the presence of large structures and the near-field effects of the siren horns exciting the LEAF chamber do not significantly disturb the homogeneity of the



chamber's sound field, except in the lowest 31.5 Hz centre frequency octave band. Here the rather small number of chamber acoustic modes gives rise to narrow uneven frequency band spectra which increase nonlinearly with sound intensity.

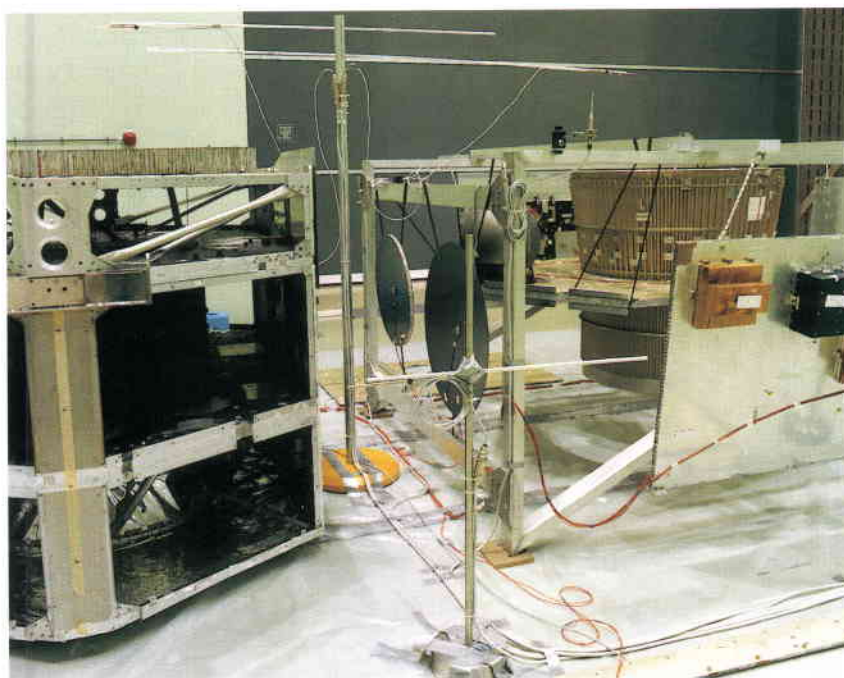
Helium is much lighter than air and has a speed of sound which is some three times greater. As a result there is a large mismatch between the impedances of air and helium (a ratio of about 2.5). This means that much less sound penetrates a helium-filled fairing. In addition, because the speed of sound is higher the number of acoustic modes that can be excited within the fairing is reduced (reduced modal density). The nett effect is a significant reduction in structural response over most of the frequency range. However, above a certain critical frequency a significant amount of vibratory energy is radiated from the structural surface (acoustic damping). This critical frequency is proportional to the square of the speed of sound of the gas in the chamber. Thus the critical frequency is some nine times higher in helium than in air, which means that the structure becomes much more lightly damped in helium at high frequencies. However, it was found that because of the reduced sound-pressure level and acoustic modal density, there was still some drop in actual structural response compared to those in an air-filled fairings at these frequencies.

Above about 150 Hz, the structural response behaviour is nominally the same both when tested inside the fairing and alone in the LEAF chamber. This implies that the interior of the fairing is truly reverberant above this frequency.

It was also found that the introduction of adjacent structural surfaces had relatively little effect on response behaviour, thought to be due to weak coupling between lightly damped modes. The addition of a large adjacent structure did lead if anything to an overall drop in response levels by way of energy absorption and dissipation.

A further important finding confirmed that most of the internal response of equipment boxes (printed-circuit boards) was due to mechanical transmission from the platform. Only when a box was very heavy and effectively "killed" the local platform vibration did the airborne sound make significant contributions to the circuit board's response.

It was also possible to demonstrate the validity of zoning concepts. The response of a side panel with equipment mounted on it was found to be little different whether it was mounted in



the complete structural model or simply on the service module alone. Subsequent tests demonstrated that a good representation of the integrated spacecraft's behaviour could be realised if the panel was simply attached to a peripheral metal frame and tested on its own (Fig. 6).

Active noise and vibration control

An anticipated increase in low-frequency noise within the Ariane-5 payload fairing during launch compared with Ariane-4 led to the successful introduction by Dornier of a passive 'Helmholtz resonator' noise control system, albeit with a sizeable mass penalty. Studies conducted by DASA-Dornier with Contraves

Figure 4. Miscellaneous development structures and equipment used for early investigations of the acoustics of the LEAF (Large European Acoustic Facility) chamber at ESTEC, and to assess the degree of reverberant behaviour induced within an Ariane fairing



Figure 5. DASA-Dornier (D) and Oerlikon-Contraves (CH) successfully developed the Ariane-5 fairing with its passive noise-control system, shown here with the Olympus test structure used to assess acoustic performance in the LEAF

Figure 6. Example of zoning: the equipment-box responses were reproduced over most of the required frequency range with the panel alone. When the panel was mounted in a metal frame, even greater correlation with the test results for the completely integrated structural model of Olympus was achieved

and TNO have now examined alternative noise-suppression techniques using novel active noise and vibration control. Initial findings substantiated by scale-model testing have shown encouraging results. Means for generating high-intensity 'counter phase' noise and for achieving a better understanding of the distribution of external noise sources require further investigation. Parallel studies are examining the efficiencies of piezoelectric actuators under space conditions.

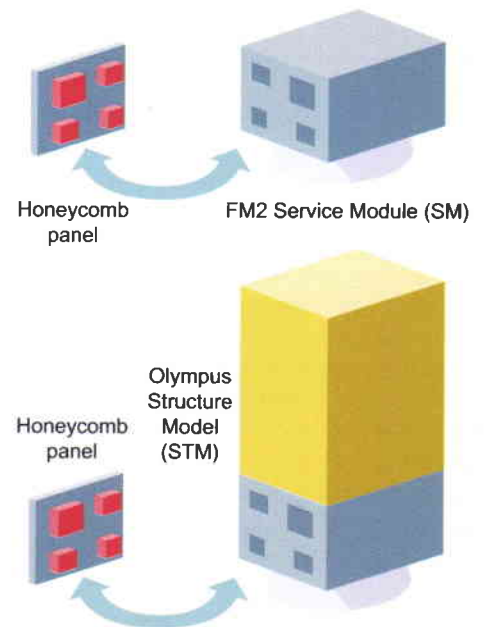
Turning from the problems of noisy launch environments to the environmental demands of manned spaceflight, the audible background noise environment within the Columbus Attached Pressurised Module (APM) of the International Space Station has to be kept within acceptable limits to allow the flight crew to execute scientific laboratory work without disruption. Additionally, such unwanted noise must not inhibit communication or induce hearing loss. Such requirements can pose severe restrictions on noise-producing equipment in the APM, given that the internal noise levels should not exceed 55 dBA in the Station's habitable areas if the crew are to be able to work with optimum efficiency whilst in orbit.

There are usually severe constraints in attempting to deal with the noise-generation mechanisms within the individual items of equipment. Investigations are in progress to provide quantitative information about novel noise-reduction tools for the treatment of radiated and transmitted noise. These studies are expected to provide worthwhile improvements over traditional methods.

A typically important problem is the transmission of tonal or near-tonal noise around the cabin-air-loop ducting. This is usually more difficult to eliminate than the general background noise, which can be dealt with by conventional passive means. Active noise- and vibration-control techniques are being studied by a DASA-led team with a view to suppressing noise generated by typical ventilation fans and by any ensuing noise augmentation due to turbulence at bends in, and by structural vibration of the ducting wall.

Microvibrations and their treatment

Microvibrations can be of concern for microgravity and optical payloads such as the SILEX laser optics telecommunications payload which will be flown on the upper platform of ESA's Artemis spacecraft (Advanced Relay and Technology Mission Satellite). This platform must maintain an incident-beam tracking accuracy of better than 0.2 arcsec.



Disturbances may emanate from such sources as momentum and reaction wheels, where dynamic forces and torques can be generated by rotor imbalances and bearing noise. Combinations of transients and more steady-state excitation can be produced by stepper motors as used for solar-array drives, attitude pointing mechanisms and mirrors. Transients can also be expected from relays.

A particular problem is the characterisation of these sources and how to introduce them correctly into any predictions used to assess the validity of the pointing budget. Prediction and testing techniques may also have to be refined if 'line of sight' direct jitter measurements cannot be attempted. These are usually application-specific, but may for example involve the interpretation of instrument mounting-location vibration measurements. The other main difficulties are the characterisation of the spacecraft structure and payload and the impact of ground as opposed to in-orbit conditions in any verification programme.

More than one approach has generally been necessary in order to establish confidence in complying with the requirements at an early stage. Special modelling has been required to represent equipment inputs where local mounting configurations can have significant effects on transmissibility. Finite-element and statistical-energy-analysis models have been used to make predictions. They have often been used to help extrapolate or scale data from ground-based tests. For example, allowance usually has to be made for

differences between ground-test and in-orbit configurations. A number of appendages such as solar arrays will not be deployed during ground tests. The importance of the effects of air in ground-based tests, in terms of mass loading at low frequencies and on damping particularly at high frequencies needs to be taken into account. Here the use of a helium tent can largely obviate the unwanted air effects and can also exclude the effects of any extraneous noise in the test area (Fig. 7).

Totally satisfactory means of attenuating excessive vibration are hard to find. Viscoelastic damping materials have properties which vary appreciably with frequency of excitation and temperature. They will creep in the presence of quasi-static loads. Electrical damping using piezo-ceramic materials is the subject of a number of investigations. Another novel approach examines the possibility of attenuating vibrations at the locations of isostatic mounts. In many optical payloads distortion due to quasi-static loads is avoided by introducing isostatic mount connections between the spacecraft platform and the equipment, often in the form of flexures. In the absence of airborne acoustic excitation, these provide the sole means of unwanted vibration transmission when in orbit. An investigation is therefore being undertaken to establish if there are ways and means of suppressing the transmitted vibrations at such locations. This could involve either passive or active damping systems, or both.

A particular approach has been adopted by CSEM (CH) to evolve a flexure in which the incurred microvibrations are magnified in a location where the damping and stiffness is



Figure 7. Helium tent used by Matra-Marconi-Space, Toulouse (F) for microvibration studies

controlled. The stiffness is provided by passive springs and the viscous damping from a linear motor. The use of electrical damping can have a distinct advantage over the use of viscoelastic material whose operational performance, in terms of its behaviour in relation to the effects of temperature and frequency, is less easy to predict.

The current configuration is called the Monolithic Elastic Element for Damping Isolation (MEDI). It effectively handles two degrees of freedom from static load transfer and vibration suppression aspects whilst minimising the stiffness in the other four degrees of freedom. A configuration of three MEDI flexures can therefore provide an isostatic system for the SILEX payload, if required. The MEDI is essentially a flexible structure which

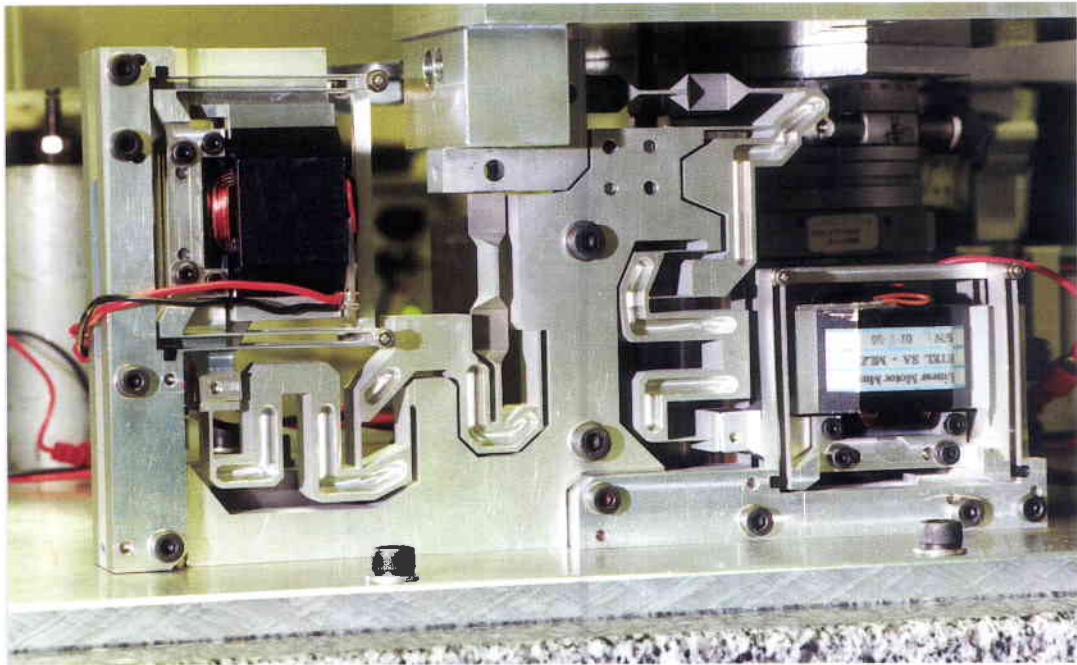


Figure 8. Monolithic Elastic Element for Damping Isolation (MEDI) developed by CSEM (CH) and Rovsing (DK)

transmits and amplifies the relative motion between the interfaces to electromagnetic damping systems (Fig. 8).

In-orbit equipment health monitoring

The Olympus spacecraft carried a micro-accelerometer system (PAX) designed to measure jitter levels of the type that might be experienced by SILEX on the Artemis spacecraft. It soon became clear that the vibration spectra produced by equipment on board Olympus could also provide data with which to check the health of the equipment items themselves. Any abnormal spectral changes were likely to indicate a deterioration. One of several such examples was the identification of an intermittent change in the behaviour of one of Olympus reaction wheels, which was subsequently rectified. An automatic signal-recognition system was developed to keep the telemetered signal from PAX under continuous assessment. This in turn has led to consideration of the development of a dedicated system for future satellites, not unlike an aircraft's black-box flight recorder. The main challenge in this respect is to devise a system that makes minimum use of spacecraft resources.

The ESA Structural Acoustics Design Manual (ESA PSS-03-204)

An accumulation of the knowledge gained from the types of problem that have been described here and the development and verification tools used in this field has led to the introduction by ESA of a Structural Acoustics Design Manual. It is intended as a reference source for use by both specialists and non-specialists.

This Manual has been developed for ESA by the Institute of Sound and Vibration Research at Southampton University (UK). It provides information on response prediction tools that can be used for structure, payload and service-equipment items subject to high-frequency vibration environments. Prominence is given to the use of Statistical Energy Analysis (SEA). Information on classical, finite-element and boundary-element techniques is also included. Appropriate empirical data are incorporated together with details of possible scaling and zoning methods. The Manual also addresses the problems of sound transmission into enclosures. Further extensions to cover the particular aspects of high-frequency microvibration and habitation acoustics are in preparation.

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MIRAS — A Two-Dimensional Aperture-Synthesis Radiometer for Soil-Moisture and Ocean-Salinity Observations

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Introduction

Soil moisture and ocean salinity are key parameters for the understanding of the Earth's climatology and the global water cycle. The Microwave Imaging Radiometer with Aperture Synthesis (MIRAS) works in a protected frequency band between 1400 and 1427 MHz and is designed to measure both of these parameters. The particular feature of MIRAS is that it achieves the required ground spatial resolution by employing a 'sparse antenna' (explained below) and using interferometry to synthesise a large aperture.

Since 1993 ESA has been conducting several feasibility studies and breadboarding activities for the development of a 'Microwave Imaging Radiometer with Aperture Synthesis', known as MIRAS. This Earth-observation instrument is intended particularly for the measurement of soil moisture and ocean salinity on a global scale. The relevance of these two geophysical parameters has been repeatedly emphasised by the scientific community and MIRAS could eventually form the core of an ESA Earth Explorer mission devoted to the global measurement of these two parameters.

Although two-dimensional aperture synthesis has been used in radio-astronomy for several decades, its application to a downward-looking sensor for Earth observation is new. Because MIRAS does not work like a conventional total-power or Dicke radiometer, it differs from them in several important respects. During the MIRAS study, much has been learnt about two-dimensional aperture synthesis for Earth observation, and the results obtained with the airborne version and its calibration system thus far have demonstrated the technical feasibility of exploiting a spaceborne sensor of this type.

How MIRAS was born

During the 1980s, in the framework of its Earth observation programme, NASA organised several workshops at which scientists

demonstrated the roles of soil moisture and ocean salinity in the global environmental system. Passive microwave radiometry could be used to measure these two geophysical parameters, but the most suitable frequency bands were those below 5 GHz and it was difficult to achieve the required spatial resolution with an antenna of reasonable size. NASA's Goddard Spaceflight Center, in collaboration with the University of Massachusetts at Amherst and the US Department of Agriculture, proposed the use of aperture synthesis as a solution to this problem for the first time and started to build an aircraft-borne prototype to test the concept. This NASA ESTAR (Electronically Scanned Thinned Array Radiometer) sensor was designed to be an L-band hybrid real- and synthetic-aperture radiometer and the instrument's validity was demonstrated in several USDA campaigns.

In May 1991, ESA organised a Workshop on 'Advanced Microwave Radiometer Techniques' in Copenhagen within the scope of a contract with the Technical University of Denmark (TUD). Leading experts from the microwave communities in Europe and the USA discussed conical scan, push-broom and interferometric techniques in an attempt to identify new avenues of research. One of the recommendations from this Workshop was the study of a two-dimensional aperture-synthesis radiometer and its calibration system, which were little understood at that time. The first step was the building of a laboratory demonstration model and this was successfully undertaken by TUD (at X-band).

In view of the recommendations of the Copenhagen Workshop and the encouraging results of ESTAR and the TUD demonstrator, in 1993 ESA initiated the MIRAS feasibility study as a 'microwave radiometry critical-technology

development' within its Basic Technology Research Programme (TRP). The contract was awarded to Matra Marconi Space (Toulouse, F).

In April 1995, the Radiofrequency Systems and the Earth Science Divisions of ESTEC co-organised SMOS, a Consultative Meeting on Soil Moisture and Ocean Salinity Measurement Requirements and Radiometer Techniques, which brought together both the international scientific community and representatives of industry. This dialogue reconfirmed the need for and importance of mapping soil moisture and ocean salinity from space.

More recently, in June 1996 on the occasion of the presentation for selection of the first Earth Explorer candidate missions, the Joint Scientific Committee for the World Climate Research Programme and the Global Energy and Water Experiment Scientific Steering Group reiterated their interest in having global soil moisture (upper 5 — 10 cm) data and expressed their wish that urgent consideration be given to an experimental soil-moisture mapping mission.

Current status of MIRAS

By the end of 1996, the MIRAS feasibility study had been completed and both the theoretical analysis of the spaceborne instrument and the development of an aircraft instrument had been performed. The success of the theoretical work, together with all of the theoretical and experimental advances related to the demonstrator and its calibration system, show that L-band two-dimensional aperture synthesis is now mature for large field-of-view Earth observation from space.

Several contracts have been started within the Technology Research Programme (TRP) and

the General Support Technology Programme (GSTP) since the completion of the initial MIRAS study, aimed at the breadboarding of the different key subsystems, namely LICEF (Light Weight Cost Effective Antenna Front-end Assembly) by MIER (E) and DICOS (Advanced Digital Correlator Unit for Aperture Synthesis Application) by DSS (D). The breadboarding of the other three main MIRAS elements - the signal harness, the structure and mechanisms and the calibration system - is expected to start in the near future, mainly through already confirmed GSTP funding.

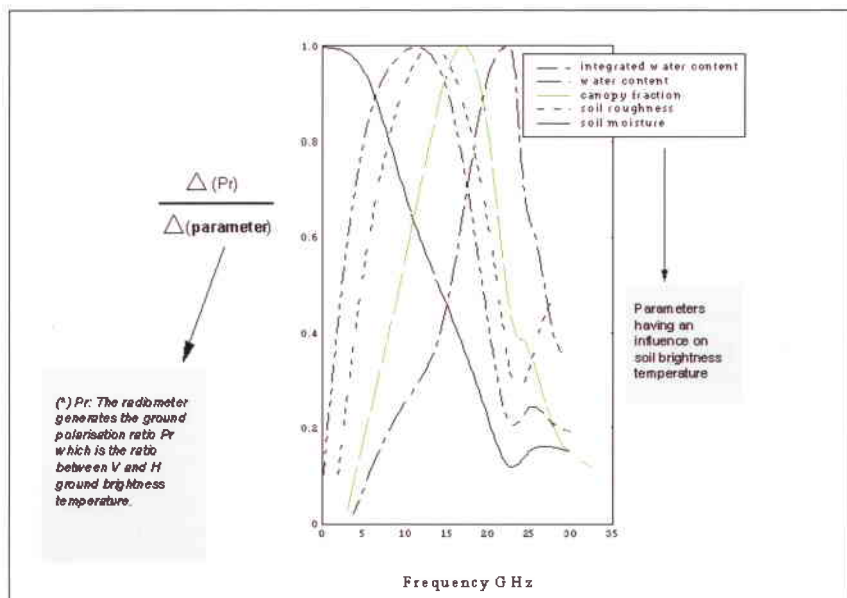
The coordination, integration and testing of all of these breadboarding activities, which will together produce a representative prototype of MIRAS, has been proposed as a Pilot Project within the new TRP programme, with the endorsement of the Earth Observation Preparatory Programme (EOPP). The MIRAS Demonstrator Pilot Project could facilitate the proposal by the scientific community of a candidate mission for the Earth Explorer Programme. Initial studies of such a mission concept have been proposed for EOPP Extension 2 in support of the next round of Earth Explorer candidates.

Scientific requirements

The scientific goals for MIRAS were established by CESBIO, taking into account the previous European and American work on soil-moisture and ocean-salinity measurements and the conclusions of the Copenhagen Workshop on Advanced Microwave Radiometer Techniques. The soil moisture, expressed in percentage terms, is defined as the ratio of water volume to soil volume in the first 5 cm of depth. The ocean salinity is defined in practical salinity units (1 psu = 0.1%), and ranges from 32 to 37 psu.

The choice of operating wavelength for MIRAS is determined by the increase in sensitivity of the brightness temperature to soil moisture (ground) and to ocean salinity (ocean) as the observation frequency decreases. L-band (1400 — 1427 MHz) is optimum because the frequency is sufficiently low and the Faraday rotation is still negligible (<0.2 deg under average conditions and <3.3 deg during magnetic storms). The sensitivity to other parameters diminishes accordingly, i.e. the vegetation and soil-roughness influence almost vanishes in the case of soil-moisture observation at L-band (Fig. 1). A key factor in the MIRAS specifications is the polarisation ratio's independence from the soil physical temperature, which leads to the choice of dual-polarisation measurements at ground incidence angles between 40 and 55 deg.

Figure 1. The choice of wavelengths for MIRAS is driven by the high sensitivity of L-band emission to soil moisture content. Dual-polarisation measurements remove physical temperature effects



Similarly, for the ocean-salinity measurements the impact of wind speed and ocean roughness on brightness-temperature measurements decreases strongly at a few GHz (Fig. 2). The water temperature's influence also diminishes at low frequencies. Nevertheless, it is useful to obtain the water temperature by using other sensors.

The scientific requirements for MIRAS are summarised in Table 1. The performance figures achieved after the various trade-offs are indicated in grey. The 3K brightness temperature accuracy, with 20/50 km ground resolution and three-day revisit cycle, are consistent with soil-moisture applications. The ocean data will be spatially and temporally averaged (in 1 deg x 1 deg zones, i.e. 111 km x 111 km, over 1 month) in order to provide the climate community with the data that it needs.

Spaceborne instrument

The spaceborne instrument collects the flux radiated by the Earth's surface via an antenna array tilted by 31.2 deg with respect to nadir (Fig. 3). This array consists of 133 elements with 70 deg half-power beamwidth distributed along three equi-spaced, 8.3 m-long coplanar arms. They operate in dual linear polarisation (horizontal and vertical). Each antenna is connected to an MMIC L-band receiver which amplifies and down-converts the H and V signals sequentially (Fig. 4). After one-bit digitisation (sign operator), the baseband digital signals are routed to the correlators via optical fibres, to minimise the effects of gain and phase drifts. The 8778 correlations, which are simply the complex multiplication and integration of any pair of receiver outputs, are performed by 1 bit digital correlators implemented in a single piece of equipment. MIRAS weighs 230 kg and consumes 300 W of power.

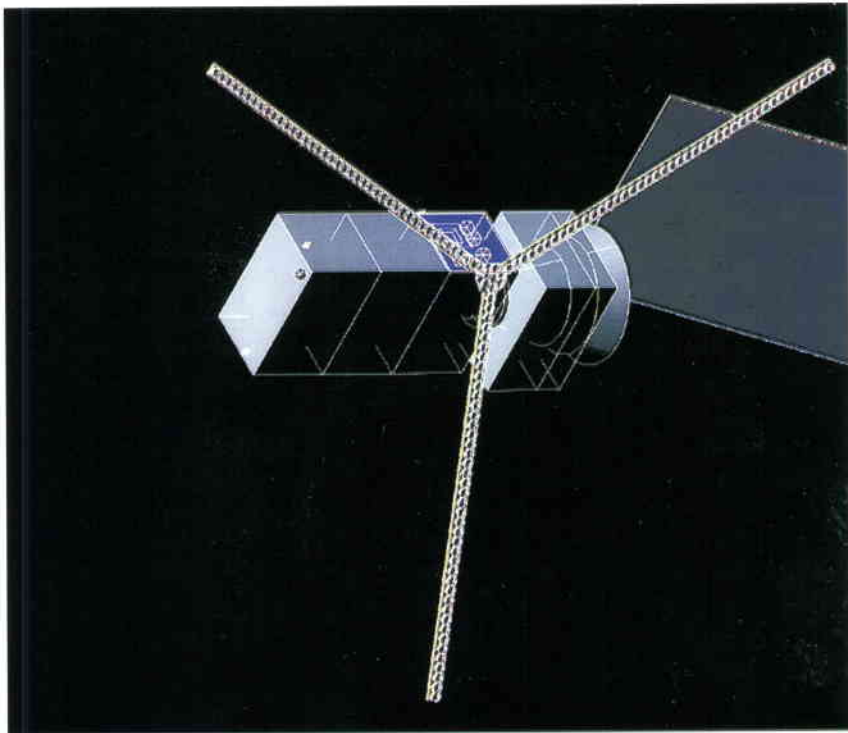
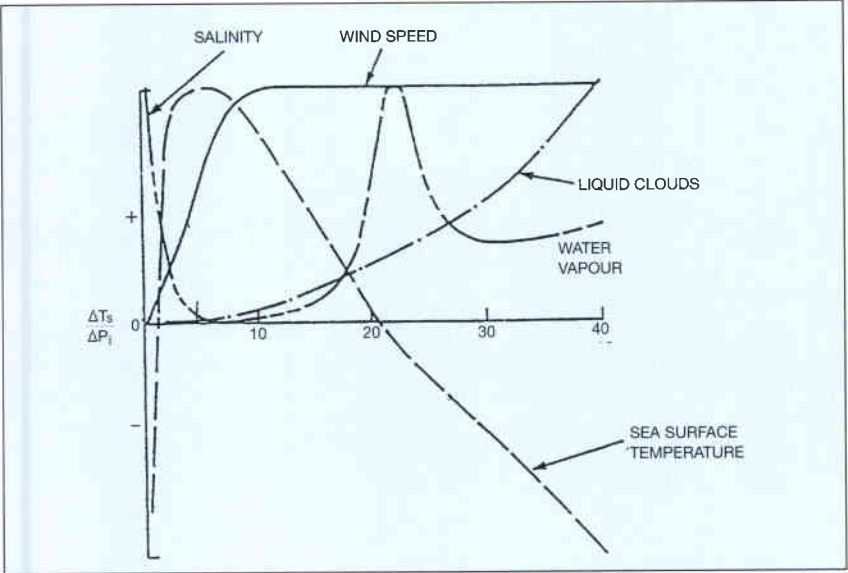


Figure 2. Over the ocean, wind and surface-temperature variations are small at L-band. Still an independent temperature measurement is required for accurate salinity retrieval

Figure 3. Artist's impression of MIRAS aboard an Envisat-type platform

Table 1. MIRAS scientific requirements

		SCIENTIFIC REQUIREMENT			PERFORMANCE PREDICTED
		DESIRED	USEFUL	ACCEPTABLE (LIMIT)	
ORBIT		Polar	Polar	Polar	Polar
		Heliosync.	Slow shift	Slow shift	Heliosync.
	revisit time	0,5 days	1 day	3 days	3 days
	Time	Noon	MIMR	-	Envisat time
	Frequency	1.4 GHz	1.4 GHz	1.4 GHz	1.4 GHz
	Polarisation	H&V	H&V	H or V	H&V
SENSOR	Polarisation	45°	40-55°	0°	40-55
	Swath	global coverage	global coverage	global coverage	global coverage
	Sensitivity	0.3K	0.5K	1K	0.9K, above ground 0.5K above ocean
	Accuracy	1K	2K	3K	3K
	Resolution	<10 km	<20 km	<50km	35km
	Synergy with other sensors	MIMR	MIMR Modis	MIMR Modis	Depends upon other programs
		Modis/AVHRR			
		WindScatt			

Figure 4. Functional block diagram of the MIRAS instrument

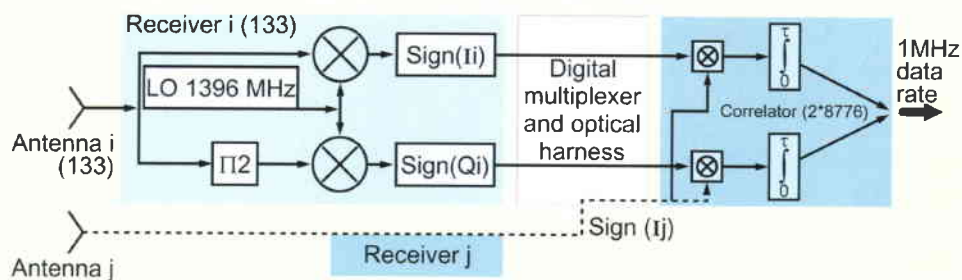


Figure 5. Left, the Y-shaped MIRAS array; right, the array's spatial frequency coverage; centre, circle of spatial frequencies in standard resolution mode

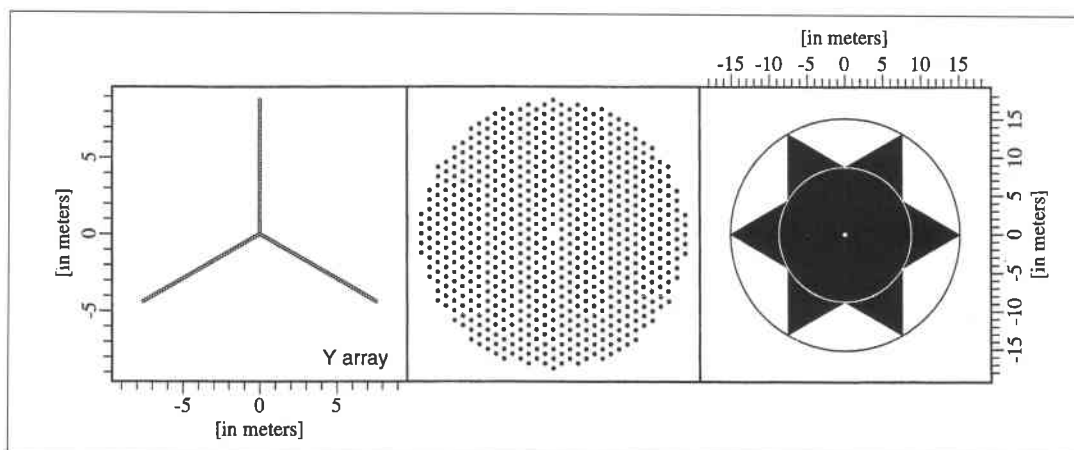
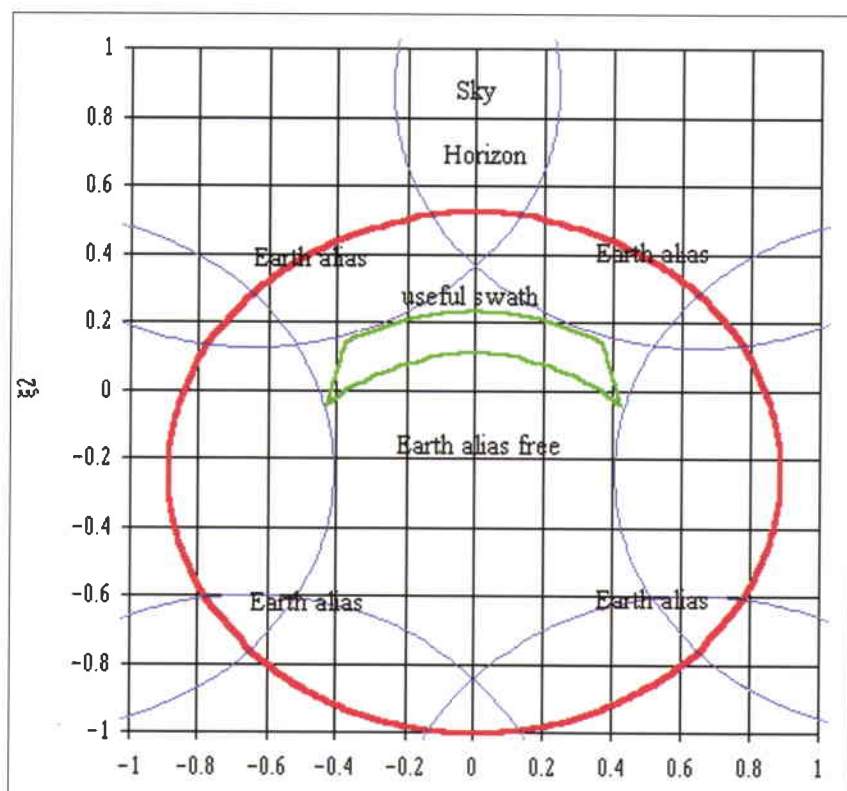


Figure 6. The useful field of view of MIRAS represented by the alias-free green box; the red contour is the Earth's disk, and the blue lines represent the Earth disk alias



The aperture-synthesis technique

The requirements for passive imaging from space of soil moisture and ocean salinity at L-band ($\lambda=21$ cm) lead to large antenna apertures (up to 20 m) for which 'thinned' arrays using aperture-synthesis principles offer clear advantages compared with mechanically or electronically steered antennas and push-

broom radiometers. A two-dimensional interferometric radiometer like MIRAS achieves the greatest degree of antenna thinning.

Several T- and U-shaped configurations with regularly spaced elements were studied for the MIRAS array. Early in the MIRAS study, the T-shape approach suited for space-platform accommodation was merged with the design used for the Very Large Array (VLA) radio telescope in New Mexico, namely a Y-shape with an exponential element distribution. The result was a Y-shaped configuration with equally spaced antenna elements, which has important advantages in terms of ground resolution and grating lobes and is suitable for spaceborne applications (Fig. 5).

The complex correlation (at zero delay) between each possible pair of antenna elements of the interferometric array gives a point of the so-called 'visibility function' at a spatial frequency defined by that particular antenna element baseline. The visibility function is ideally the Fourier transform of the brightness temperature of the scene, weighted by the element gain pattern, which can then be recovered via an inverse Fourier transform.

MIRAS's novel Y-shaped antenna achieves a dense sampling of the visibility function for a given spatial resolution, the larger spacing between antenna elements compared to rectangular arrays leading to savings of 13% in

antenna/receiver elements and 28% in the number correlators needed.

MIRAS's useful swath is a defined region more than 900 km wide, comprising all incidence angles between 40 and 55 deg (green domain in Fig. 6). Its element spacing has been increased beyond the strictly alias-free limit to the point where only the useful swath remains alias-free, resulting in further hardware savings (Fig. 6).

Performance

In a standard-resolution mode (only the visibility-function samples inside the small circle in Fig. 5 are taken), the antenna half-power beam width is 1.2 deg, corresponding to a worst-case ground resolution of 35 km. Even with this narrow reconstructed beam, the beam efficiency of MIRAS is better than 93%.

The radiometric sensitivity of the MIRAS snapshot is greater than that of the corresponding conventional real-aperture radiometer by the array filling factor. This loss of sensitivity is, however, recovered via the larger integration time available in the case of the interferometric radiometer. MIRAS's sensitivity is 0.9 K over land and 0.5 K over the ocean.

Phase restoration

Antennas and receiver chains are likely to be affected by phase errors. Their impact on the visibility function is partially cancelled thanks to the phase closure properties which allow the phase of the visibility samples to be recovered via a phase-restoration algorithm. The effect of in-plane array deformation is also cancelled by this means.

Airborne demonstrator

The second half of the MIRAS contract was devoted to a demonstration of the spaceborne sensor's capabilities by flying a scaled-down



Figure 7. An 11-element L-band MIRAS aircraft breadboard suitable for a Hercules C-130

instrument on an Hercules C-130 aircraft. The central core of this MIRAS breadboard is identical to that of the spaceborne instrument (Fig. 7), with a Y-shaped antenna with 0.65 m-long arms and 11 antenna elements in total. One additional element outside the Y-array provides the phase-restoration capability. The aliasing conditions onboard an aircraft are different from those on a spacecraft, but an aliasing-free region exists in MIRAS demonstrator field of view for the 50 deg ground incidence cone when the antenna array is tilted by 45 deg from nadir. Both V and H polarisations are sent alternately to the receivers. Every 3 or 5 s, according to operator selection, calibration signals are also presented at the receiver's input ports: either independent (uncorrelated) loads supposed to produce a zero output, or correlated signals supposed to produce a known output.

The MIRAS airborne demonstrator has addressed several system issues as well as critical technologies which are briefly discussed below. The calibration system has also been

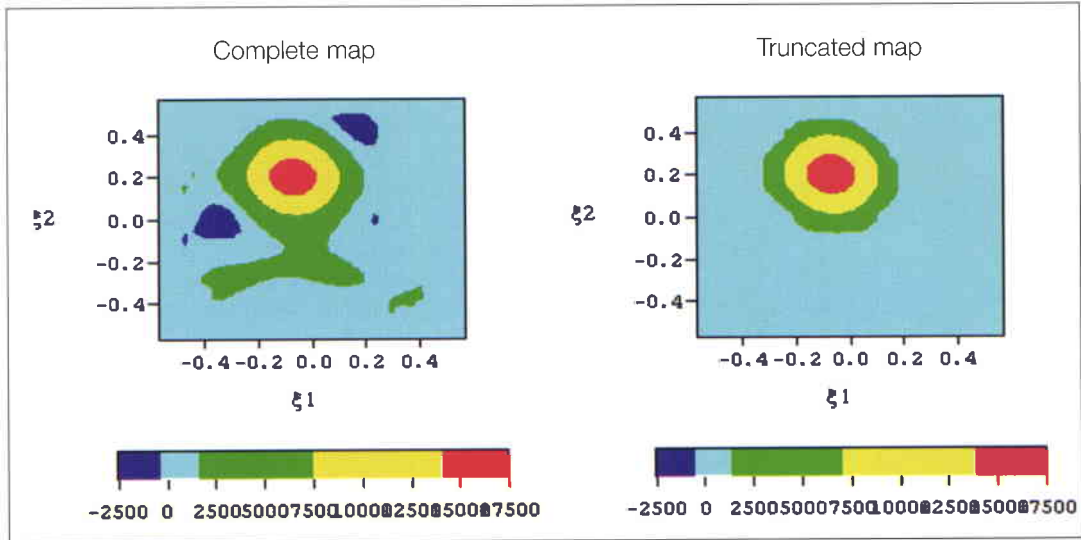
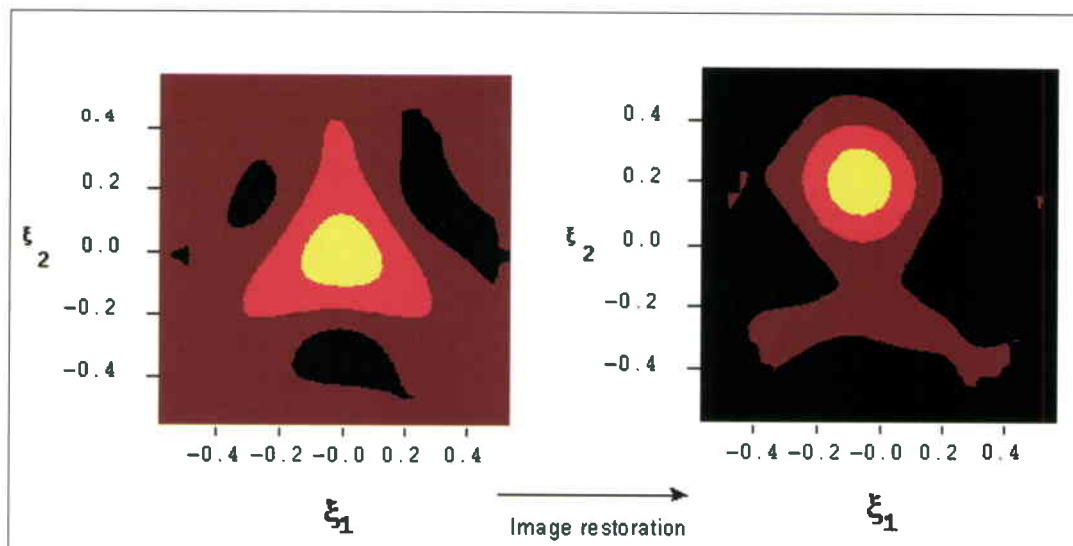


Figure 8. Measurement of spatial resolution and beam efficiency

Figure 9. Testing of the phase-restoration algorithm using a noise source in the near field of the MIRAS breadboard

A near field point source generates aberrations in the reconstructed image (left image). The near field influence, in the case of a point source, is mainly a phase error applied to each antenna receiver chain. This phase error is fully corrected by the phase restoration algorithm, as demonstrated by the right-hand image. A phase offset remains (displacement of the reconstructed spot) which can be calibrated out



investigated using the demonstrator, and is addressed separately below.

System aspects

- Spatial resolution and beam efficiency

The spatial resolution obtained with the airborne demonstrator is about 15 deg, as predicted, and the beam efficiency is 72%, which is lower than for the spaceborne MIRAS as expected from the reduced number of elements (Fig. 8).

- Radiometric sensitivity

The system's radiometric sensitivity has been verified. The average value of the standard deviation across all visibility samples when MIRAS is inside an anechoic chamber at about 300 K is 0.35 K, which translates into a radiometric sensitivity in the reconstructed

brightness temperature of 0.5 K at the centre of the image and 1.15 K at the edge, for an integration time of 0.3 s.

- Phase restoration

The phase-restoration algorithm has been tested by using it to correct for the aberrations produced in an image of a point noise source located in the near field of MIRAS. The induced phase error is fully corrected by the phase restoration algorithm (Fig. 9). The corrected image appears shifted, but this displacement can be calibrated out.

Critical technologies

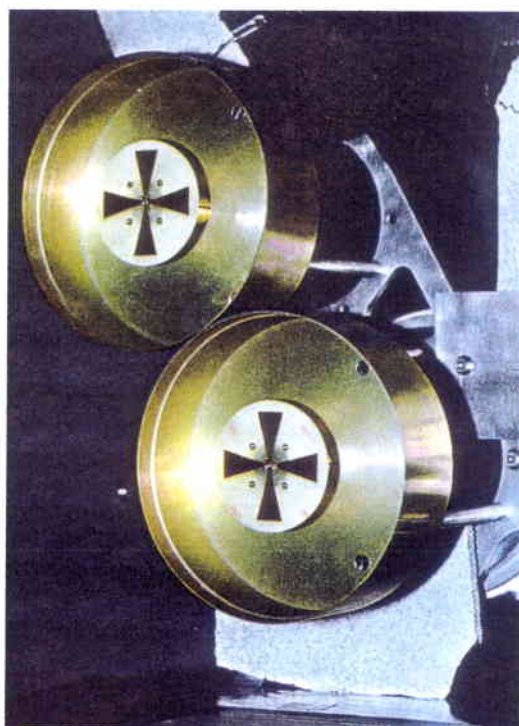
- Antenna elements

The 11 dual-polarisation cup dipole antenna elements of the MIRAS airborne demonstrator have been manufactured and tested. Their radiation patterns are very similar, with directivities between 9 and 9.2 dB for 18.5 cm aperture diameter, including the effects of the thermal-box side walls simulated during the measurement (Fig.10). The half-power beamwidth is between 65 and 70 deg, depending on direction and polarisation. The normalised phase discrepancy between antennas is less than 5 deg within the instantaneous field of view. The cross-polarisation level is -20 dB, but -30 dB inside the IFOV. The coupling between antennas is better than -25 dB.

- Microwave receivers

The low-noise amplification, filtering, and I and Q demodulation in MIRAS are performed by 11 units installed around the structure, phase-locked to a common reference clock signal which is distributed by optical fibre (Fig.11). The demonstrator receivers are similar to the spaceborne ones apart from their analogue (instead of digital) IF output, the one-bit digitisation being achieved in the correlator unit.

Figure 10. Measurement of the antenna pattern of the MIRAS breadboard simulating the side walls of its box



As for the receiver response, the design goal was to achieve flat in-band gain and group delay, which is a challenge considering the 100 dB gain and the filtering of potential out-of-band interference.

- Correlator unit

The MIRAS demonstrator requires 55 complex (or 110 real) correlators. They are implemented in a single 10 dm³ unit based on FPGA circuits for the digital sections. No particular effort has been made to meet, or even approach, the spaceborne correlator's power consumption and mass. The correlator unit receives a number of noise video signals from the microwave receiver assembly to perform the correlations. Each receiver provides two inputs to the correlator unit, the in-phase and quadrature signals.

The correlation measurement is based on a 1-bit by 1-bit multiplication, sampled at the Nyquist rate of the incoming video signal (> 50 MHz) and the result accumulated during a (snapshot) integration time of 0.3 s. The 300 ms clock is generated by the correlator unit. The correlation results, which constitute the visibility function, are provided in a digitised form. The correlator unit also measures, averages and digitises the Power Measurement Signal (PMS), which provides the total brightness temperature of the scene. The integration time is synchronised with the 300 ms clock. The visibility and PMS data, together with the housekeeping data, are multiplexed and transmitted to the data-management unit.

The two critical performances of the correlators are the noise and the accuracy. As demonstrated in the 1-bit correlator theory, the

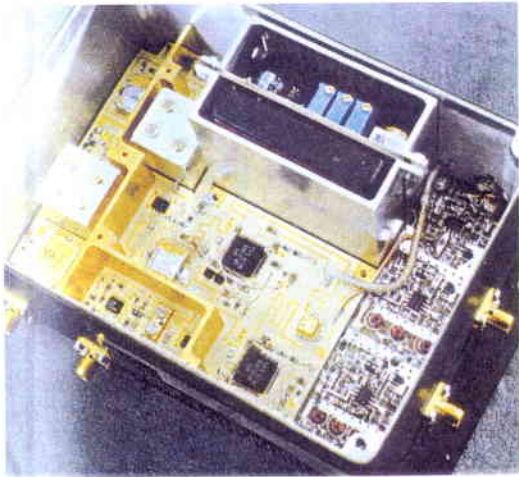


Figure 11. The microwave receiver unit, 11 of which were manufactured

signal-to-noise ratio (S/N) is equal, for small correlations, to 0.64 times the analogue correlator S/N. MIRAS correlators fit perfectly with the theory, with no additional noise being observed. As far as accuracy is concerned, it was found during the measurements that the major contributor is the test setup digital voltmeter linearity. Measured with independent noise input signals, some correlation offset errors are as low as 10⁻⁴, whilst others reach 3 x 10⁻³. This has a negligible impact on MIRAS performances (Fig. 12).

Calibration system

In the MIRAS demonstrator, the image-reconstruction process assumes identical antenna patterns and identical transfer functions for the 11 receiver chains. The mutual coupling between antennas is assumed to be negligible, as well as the decorrelation effect at large viewing angles from the boresight (the so-called 'fringe wash factor'). Those assumptions enable a straightforward image reconstruction and give a very good result in the case of the MIRAS demonstrator. In a real

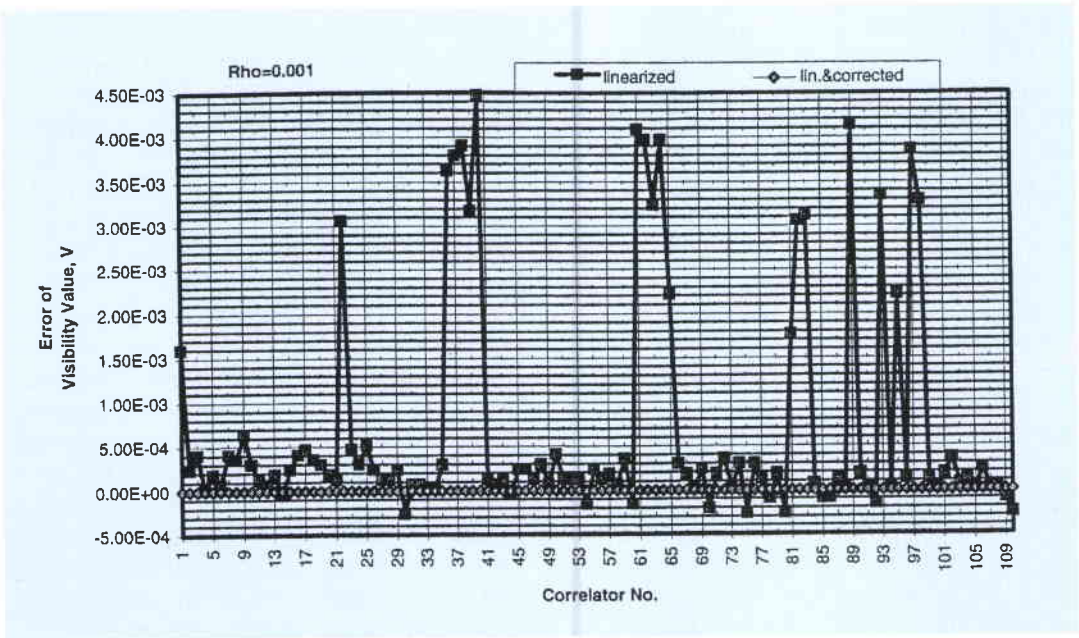


Figure 12. Measured performance of the correlator unit of the MIRAS breadboard (correlation error after offset calibration is less than 10⁻⁴)

instrument, the receiver bandwidth centre frequencies and group delays are slightly different, the antenna radiation patterns are not identical, and the antenna mutual couplings are not null. All of those discrepancies have to be taken into account to achieve the ultimate image accuracy. Such a study has been accomplished in parallel with the MIRAS demonstrator's development, and the results are briefly presented below. In the meantime, a powerful Fourier transform using hexagonal sampling has been proposed based on methods available in the literature.

Identification of instrument errors

The instrument errors that can play a role have been classified into three categories:

- *Antenna errors*, which affect each antenna element independently:

These are pattern phase ripple, pointing and position errors, and antenna V/H cross-talk.

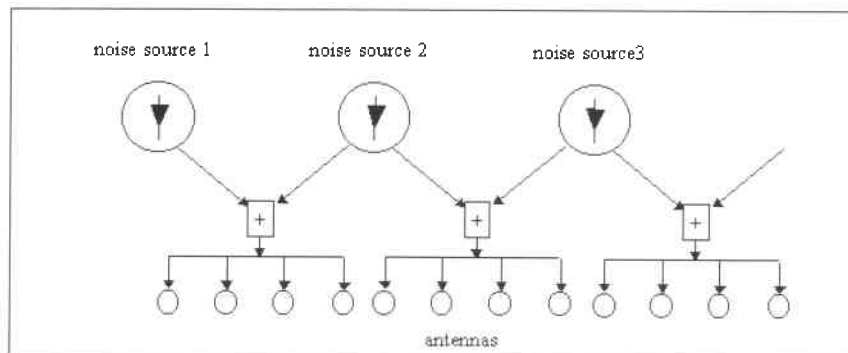


Figure 13. Distributed network of correlated overlapping noise sources for MIRAS calibration

They are completely compensated for by the iterative reconstruction algorithm, provided that their initial diagram patterns are known exactly, or are measured in flight using known scenes.

- *Receiver errors*, which affect each receiver independently: in-phase and quadrature errors, channel gain errors.

- *Baseline errors*, which affect each pair of antenna-receiver chains independently:

Phase, gain and offset errors as well as channel group-delay errors and frequency response.

Hardware calibration system

A centralised common noise-source reference as implemented in the MIRAS demonstrator enables the calibration of both the receiver and baseline errors. However, such a coaxial distribution network is critical in the case of the spaceborne instrument because of mechanical constraints at arm hinges. The phase stability of the reference signal is also questionable. An alternative calibration system is therefore proposed for the spaceborne instrument based on a distributed network in which several reference sources feed overlapped groups of

antenna/receiver chains (Fig. 13). It achieves the calibration of all receiver errors and the separable part of the baseline errors. The non-separable contribution in the baseline errors cannot be calibrated out with the distributed noise injection and must be minimised and bounded by the error in estimating the visibility amplitude and phase.

In addition to the correlated reference signal, another calibration signal is provided to calibrate out correlation offsets. This signal is generated by independent matched loads connected at the time of calibration to the input of each receiver.

Calibration process

From the results obtained with the airborne demonstrator and the related studies, the best calibration system for the spaceborne MIRAS instrument is one based on the injection of correlated and uncorrelated noise, followed by the phase restoration technique.

Image reconstruction

The baseline image-reconstruction algorithm assumes identical antenna patterns and receiver frequency responses. An iterative algorithm has been defined to solve the equation set describing the complete system. As an example, a 31-antenna MIRAS-type radiometer has been simulated with antenna and receiver discrepancies. A synthetic scene is perfectly reconstructed after just four or five iterations (Fig. 14). Despite the system complexity, the spatial and radiometric resolution are not degraded compared to the inverse Fourier transform used for the ideal system.

Other related studies

Within the scope of the MIRAS contract, two further studies have also been performed which are worth mentioning here: one covering a dual-frequency MIRAS, and one covering a MIRAS demonstrator for small-satellite applications.

Dual-frequency MIRAS

While a single-frequency, dual-polarisation L-band MIRAS sensor is capable of providing soil-moisture observations on its own, retrieval of ocean salinity is possible only with an independent measurement of the sea-surface temperature. In order to provide that independent observation, a dual-frequency MIRAS has been studied. The scientific analysis has shown that a C-band channel can do the job and both the antenna array and the receiver architecture have been analysed. Once again, an extremely convenient array solution for space-borne applications has been found (Fig. 15).

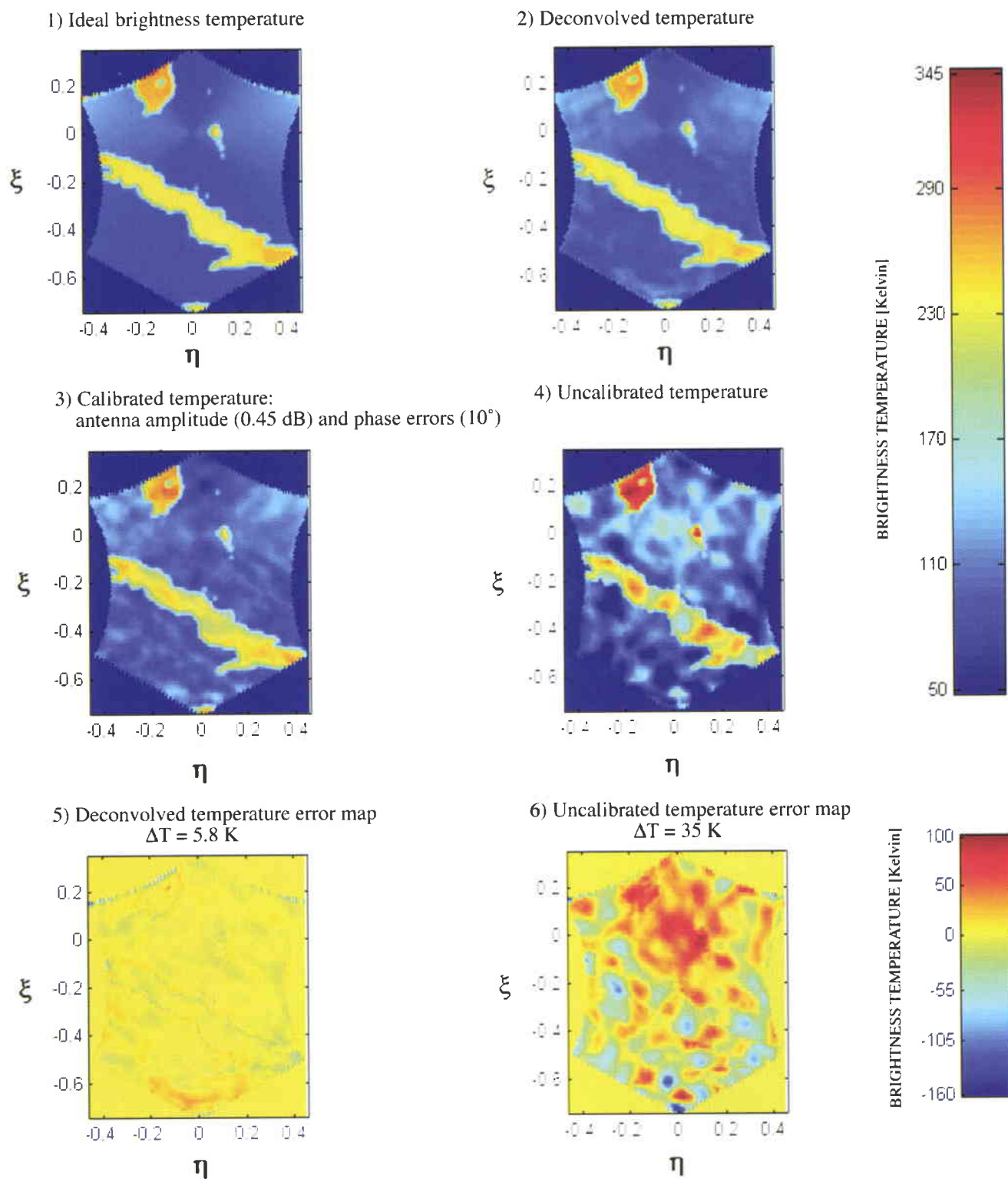
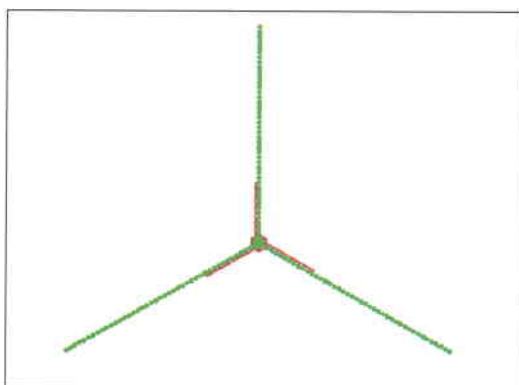


Figure 14. Iterative image algorithm tested on a synthetic scene (Cuba and Florida)

Figure 15. Dual frequency MIRAS array. The C-band interferometer is also full-phase with an homothetic spatial frequency coverage as compared to the L-band array and the same spatial resolution



The C-band array can be easily accommodated mechanically while preserving all of the required interferometric and performance features of the L-band array. The overall mass and power consumption of the dual-frequency MIRAS have been estimated at 300 kg and 600 W, respectively.

MIRAS demonstrator for a small satellite

The main MIRAS contract focused on compatibility of the instrument with an ESA platform of the Envisat type. A short study has been carried out of a reduced MIRAS sensor suitable for small-satellite applications. With an arm length of just 5 m, it is still able to provide valid scientific data at 50 km ground resolution from a 672 km-high Sun-synchronous orbit. Its compact configuration when stowed allows small commercial launchers to be used. Compatibility of this sensor with the Minisat (E) platform has been preliminarily assessed (Fig. 16). It has been proposed that the array geometry and pointing be measured in-flight by placing GPS antennas at the tips of the antenna arms and applying double-difference carrier phase processing. The estimated mass and power requirements are 180 kg and 230 W, respectively.



Figure 16. Presentation of the MIRAS demonstrator on the Spanish Minisat at the International Conference on Small Satellites: Missions and Technology, in Madrid in September 1996 (Mockup courtesy of Sener, Spain)

Conclusion

With MIRAS being based on interferometric principles, much research has been performed at all subsystem levels, from the key geometry of the antenna array to the calibration system for correlated/uncorrelated noise injection, from the theoretical fundamentals to the image processing through iterative methods based on Fourier transformation over hexagonal sampling grids. The airborne MIRAS demonstrator that has been built and tested has performed successfully and in accordance with the predictions. A great deal has been learnt and the results obtained so far with the airborne instrument and its calibration system have shown that L-band two-dimensional aperture synthesis is now a mature technology for large field-of-view Earth-observation from space, paving the way for a candidate Earth Explorer mission devoted to soil moisture and ocean salinity.

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Sharing Mission Data via the Internet

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Introduction

Satellite missions are always performed to achieve well-defined goals. However, these goals would be incomplete if the data produced by a mission were not delivered to end users. In the past, data was often delivered on media that required postal shipment for final delivery. Recent technological developments in networking and a larger interest for networked applications are making the Internet a very attractive alternative in delivering mission data. The system used to distribute mission data to the user community is often referred to as the 'Data Distribution System (DDS)'.

On reception at the Control Centre, spacecraft data is routed, together with the relevant auxiliary data, to the Data Distribution System (DDS) where it is available in near-real-time. End users (for instance, Principal Investigators or other members of the scientific community) may be allowed access to this data on-line via the Internet as well as off-line via appropriate Mass Delivery Media (MDM). The users may also be allowed to select data according to predefined mission-dependent criteria (e.g. experiment, experiment mode, time range, data quantity) and retrieve it to their local computers for further analysis. To provide a standardised format for the data delivery, on-line and off-line data may be encapsulated in a Standard Formatted Data Unit (SFDU) as per the recommendations of the Consultative Committee for Space Data Systems (CCSDS).

In support of this data distribution approach, ESA has developed a generic Control Authority Office (CAO) system* to handle the on-line registration and dissemination of data descriptions relative to the mission data that is available to external users.

Distinct advantages of using Internet technology include the speed and efficiency with which the data can be delivered, and the fact that more sophisticated data selection can be exercised by end users. This means that a user interested in a limited part of the data can electronically request and receive just that particular data set.

The Consultative Committee for Space Data Systems (CCSDS), a standardisation body that represents most space agencies, has produced recommendations for the Control

Authority Office (CAO). The goal of the CAO is to make descriptions of mission data available to users in an organised and simple manner. The CCSDS concept foresees that each CCSDS-participating space agency has one or more CAOs, each managing and maintaining mission-specific data descriptions. ESOC took the lead in the context of CCSDS Panel 2 in developing a CAO system that is compliant with the CCSDS recommendations and with which the user community can interact via the Internet.

In this context, it is likely that future missions will make more and more use of the Internet to distribute mission data and to deliver the necessary services to guarantee long-term (actually indefinite) data documentation. This does not imply that the Internet will be the only mission- data transfer medium of the future. In fact, depending on the quantity of mission data that needs to be transferred, the size of the user community that wishes to access this data and how quickly the data is required at the end-user site, other media might be preferable. These media, which require physical shipment to the end user (for instance, postal mail), are referred to in this article as 'Mass Delivery Media (MDM)' and currently include compact disks (CD-ROM), digital audio tapes (DAT) and magnetic disks.

Nevertheless, even if MDM were selected by a mission as its primary data transfer medium, Internet access to a limited portion of the data might still provide useful services, for instance in allowing users to quickly inspect the quality of the data prior to ordering it on MDM. This would avoid unnecessary MDM production costs. The user could also place the MDM order via the Internet and even 'compose' a customised MDM carrying specially selected mission data.

The term 'Internet' does not exclude the use of a dedicated line or network. In fact, in some cases, this can be the most convenient approach in fulfilling delivery-rate and security requirements.

* The current release of the ESA CAO system is available at http://cao.esoc.esa.de/cao-bin/cao_home to all users with World Wide Web and socket interfaces.

End-to-end data flow model

In the context of this article, mission data consists of all the data from a given space mission that is of interest to its user community. Typically, this includes spacecraft data in raw or pre-processed forms and auxiliary data – the latter usually being the information that is needed by the user community in order to meaningfully interpret and process the spacecraft data.

Figure 1 depicts a typical end-to-end data flow model for sharing mission data with the user community. Note that it is not the intention to impose a system architecture, but rather to provide a model that should help to define the end-to-end system functionality. Spacecraft data is received by the Mission Control System (MCS) from the ground stations. In addition to being used for spacecraft monitoring and control, spacecraft data together with all the relevant auxiliary data are made available (pre-processed or not depending on the mission requirements) to the back-end of the MCS, the Mission Exploitation System (MES) and, in particular, to the Data Distribution System (DDS).

A user community member who is interested in receiving mission data can prepare a request (see step 1, Fig. 1) on his local computer and submit it via the Internet to the DDS. Upon receipt, the DDS interprets the request, prepares the requested mission data and returns it to the user via the Internet (step 2a, Fig. 1) or via MDM (step 2b, Fig. 1). In the second case, some form of physical shipment (e.g. mail) is needed.

As a result, the user will have the requested mission data available locally on his computer, but will still need more information in order to interpret it. In an ideal situation – the one modelled here – all mission data delivered by the DDS is encoded in Standard Formatted Data Units (SFDU). As shown schematically in Figure 2, the SFDUs are recommendations for standard data structures developed by the CCSDS that provide a method for labelling data objects and linking them to a unique description. By reading the labels on the mission data, the so-called 'Authority and Description Identifier (ADID)', the user can query the Control Authority Office (CAO) system (step 3, Fig. 1) which will return the data descriptions (DD) corresponding to the labels (step 4, Fig. 1). The DD provides the information that allows unambiguous mission data decoding and interpretation.

The existence of the CAO system might seem to be an excessive preoccupation at first glance, but it reflects a very realistic need, above all in the case of a long-duration mission or when access to the mission data is not restricted.

The Data Distribution System

The main task of the DDS is to deliver mission data to the user community. Generally speaking, the DDS provides the following two distinct services:

- the On-Line Data Delivery Service which allows interaction to the DDS via the Internet
- the Off-Line Data Delivery Service which allows off-line production of MDM.

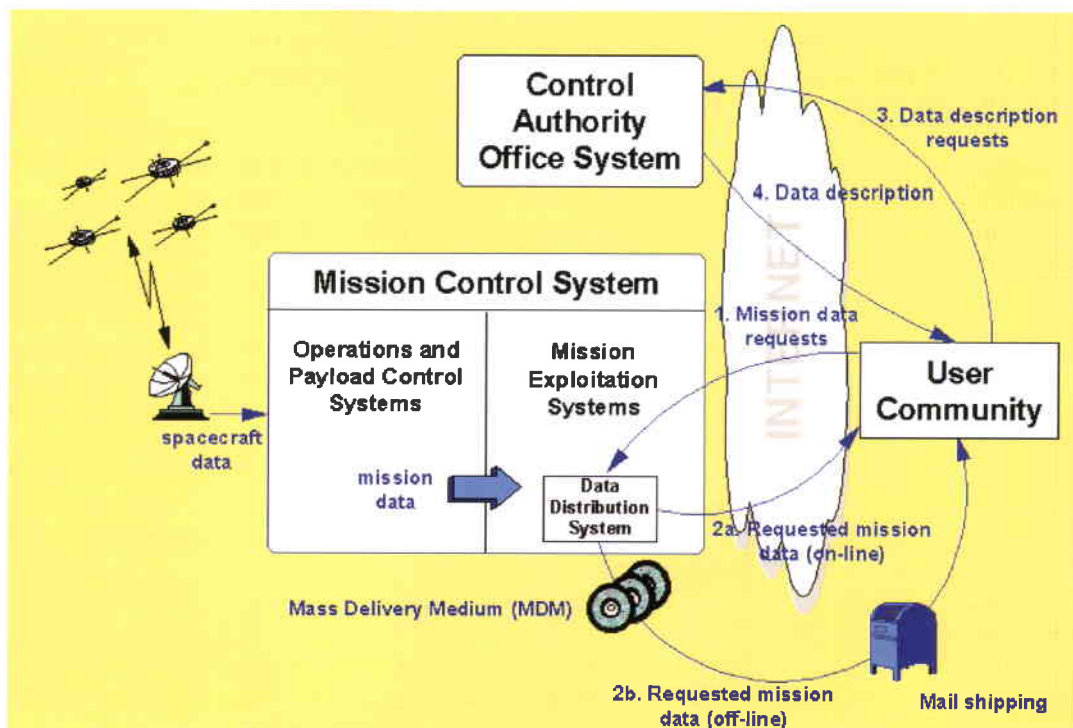


Figure 1. The end-to-end data flow model

Any mission that requires a DDS needs to define and design it based on the volume of mission data to be shipped out, the size of the user community and the speed at which data needs to be provided to the user (Table 1). For example, a mission generating a high data volume and servicing a large user community usually cannot afford to only have the on-line service because of the costs associated with providing sufficiently performant network connectivity. It would then be advisable to restrict the on-line service to a small portion of the mission data and have the bulk delivered via an off-line mechanism. Mission critical information that requires timely delivery or summary information that allows the user community to establish its interest in receiving larger volumes of mission data are good candidates for on-line access.

On-line data delivery service

The requests for on-line service may include:

- requests for catalogue information: allows remote users to query what mission data is available on the DDS
- requests for on-line delivery of specific mission data: allows remote users to select and retrieve mission data from the DDS via their local computer
- requests for off-line delivery of specific mission data: allows remote users to select mission data and to order the MDM product for shipment to their postal address
- requests for user registration: allows remote users to register with the DDS for access to mission data.

Table 1. Indicative trade-offs between on-line and off-line data delivery services based on mission data volume and user community size

Mission Data Volume	User Community Size	On-line DDS	Off-line DDS
High	High	✓	✓
High	Low		✓
Low	High	✓	
Low	Low	✓	

The way in which user requests are delivered to the DDS can vary considerably. For example, the Cluster scientific mission uses ASCII structured files transferred with the File Transfer Protocol (FTP), while XMM plans to adopt HyperText Transfer Protocol (HTTP) messages.

The protocol of the responses from the DDS to user requests also varies from project to project. For example, Cluster uses SFDU-encoded files transferred with FTP, while XMM plans to adopt HTTP messaging (although use of SFDU is currently under discussion).

Off-line data delivery service

The on-line and off-line data delivery services may be totally independent of one another although both may use the same mission data pool. For instance, this service may be wholly controlled by the DDS and not require any input from external users (as in Cluster) or be user-triggered via the Internet (as planned by XMM). In any case, once the DDS receives the order to produce one or more MDMs, it retrieves the data needed and starts the production process. As a general rule, the MDM and its

Table 2. Comparison between Cluster and XMM Data Distribution Systems

	CLUSTER	XMM
Computer platform	VAX 4000-105A	Distributed system involving SUN and NT platforms
User community	Pre-defined list of about 20 users	Entire astronomical community
Mission data available on-line	Last 10 days of mission data	Entire mission
On-line data delivery service	Yes. — Requests for catalogue information — Requests for on-line delivery of mission data for quick-look	Yes. — Requests for catalogue information — Requests for on-line delivery of mission data for quick-look — Requests for off-line delivery of specific mission data — Requests for user registration
Protocol for on-line requests	ASCII structured files transferred with FTP	HTTP messages
Protocol for on-line responses	SFDU-encoded files transferred with FTP	HTTP messages (SFUD TBD)
Off-line data delivery service	Yes. Automatic daily production of CD-ROMs for a selected distribution list	Yes. Automatic and on-demand (Internet) production of CD-ROMs
Mission Delivery Medium (MDM)	CD-ROM	CD-ROM
MDM standard	SFDU-encoded CD-ROM compliant with ISO 9660 level 1	CD-ROM compliant with ISO 9660 level 2 (SFUD TBD)
Data descriptions registered with CAO	Yes	TBD

format should comply with internationally recognised standards to ensure maximum portability across platforms. To fully exploit the potential of the Control Authority Office concept, it is highly desirable that the data on the MDM be SFDU-encoded, as is the case for Cluster and is currently under discussion for XMM (Table 2).

The Control Authority Office system

Background

With the large quantities of space science data being produced by today's space data systems, the format of the data is often not sufficiently well documented to allow users not directly involved with the systems to exploit the data. This is particularly the case where the data archiving is long-term and people with detailed knowledge of the data are no longer available.

To address this problem, the CCSDS has defined the CAO mechanism for ensuring that descriptions of data, are always easily accessible and available to users. It is part of the CCSDS SFDU concept explained above, which defines standardised methods for encapsulating data for exchange between providers and users (Fig. 2).

Clearly, the data descriptions could be packaged with the data, giving the advantage that the descriptions are immediately available to the user receiving it. The disadvantage, however, is that if the same format of data is sent repeatedly, for instance in case of spacecraft telemetry frames, then the same data descriptions need to be sent over and over, leading to unnecessary overhead. For this

reason, the CAO concept handles the registration, revision and dissemination of data descriptions that do not accompany the data which they describe.

Each CCSDS member agency is obliged to nominate a primary Member Agency Control Authority Office (MACAO) with overall responsibility for the data descriptions registered at that agency. ESOC has been nominated as the primary MACAO for ESA.

The CCSDS has published two recommendations relating to Control Authority responsibilities and procedures. The top level recommendation is the 'Standard Formatted Data Units - Control Authority Procedures' Blue Book. This outlines the purpose of the Control Authority and the procedures that must be followed by the agencies conforming to the standard. It includes procedures for establishing a primary MACAO and any derivative MACAOs, the registration, dissemination and revision of data descriptions (the primary tasks), and the relevant reporting procedures.

The second recommendation of the CCSDS is the 'Standard Formatted Data Units - Control Authority Data Structures' Blue Book. This builds on the top level recommendation by presenting an automated method of interacting with a Control Authority. Standard SFDU structures are defined for carrying the information that is required for registration, dissemination and revision of data descriptions, plus standards for the representation of the necessary information. This recommendation relies upon the electronic transfer of the

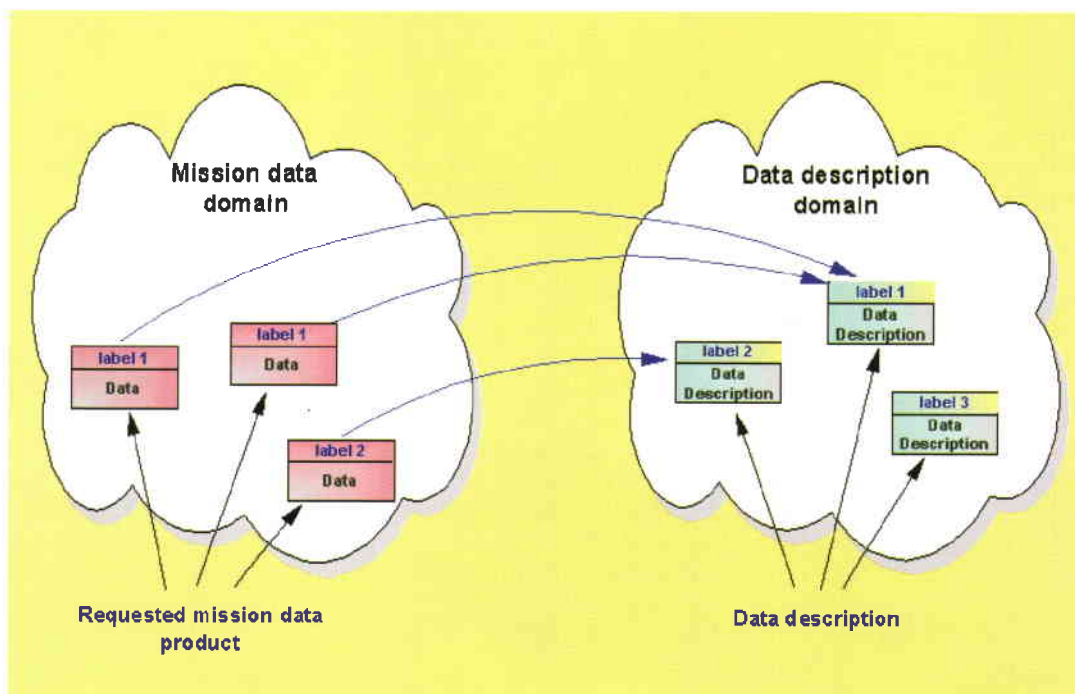


Figure 2. The relationship between SFDU-encoded data and its data description

necessary information, it does not specify whether the transfer should be via physical magnetic media (e.g. disks or tapes), network transfer or an interactive form interface.

The ESA generic Control Authority Office system

As mentioned in the introduction, ESA took the lead within Panel 2 of CCSDS in developing a generic CAO system that would fulfil the CCSDS recommendations and that could be distributed as public domain software (free of charge) to any space agency that would require it. All of the software components necessary to run the ESA CAO system have therefore been selected so as not to require the payment of any licence fees. The system runs on a SUN/Solaris platform.

As defined by the CCSDS recommendations, the ESA CAO system supports the following services:

- user registration: allows the registration of a user as data description provider or reviewer. Each registered user has a password which allows selective access to CAO functionality
- data description registration: allows the registration of data descriptions by data providers. During registration, the data descriptions are assigned an Authority and Description Identifier (ADID). This unique identifier is used within SFDUs to reference this unique data description
- data description dissemination: allows the dissemination of data descriptions either directly, by giving the required ADID, or by entering search criteria on other available information
- data description revision: allows the revision of data descriptions when they change
- production of summary information: allows the CAO system administrator to generate the annual report as per CCSDS recommendations.

The current version (3.0) of the ESA CAO system (Fig. 3) supports two types of interfaces:

- World Wide Web (WWW) interface: allows data providers to register and revise data descriptions by entering information via a set of WWW forms. The registered data is stored in a data description database. When a user requests that a data description be disseminated, that description is retrieved from the database and displayed on a Web page. To access these services, a user simply needs a Web browser (such as Netscape or Mosaic)
- socket interface: allows a user's application to interact directly with any instance of the ESA CAO system (machine-to-machine) via an Application Programmer Interface (API). The user application (client side) can query the ESA CAO system (server side) and use the data descriptions that are returned. The API has also been developed by ESA (version 1.0) and is freely available to any space agency that requests it.

The ESA CAO system is easy to install and customised configuration is possible. Each installation of the ESA CAO system can manage data descriptions for several MACAOs and has the ability to automatically forward requests for data descriptions that are not under its control to the appropriate CAO

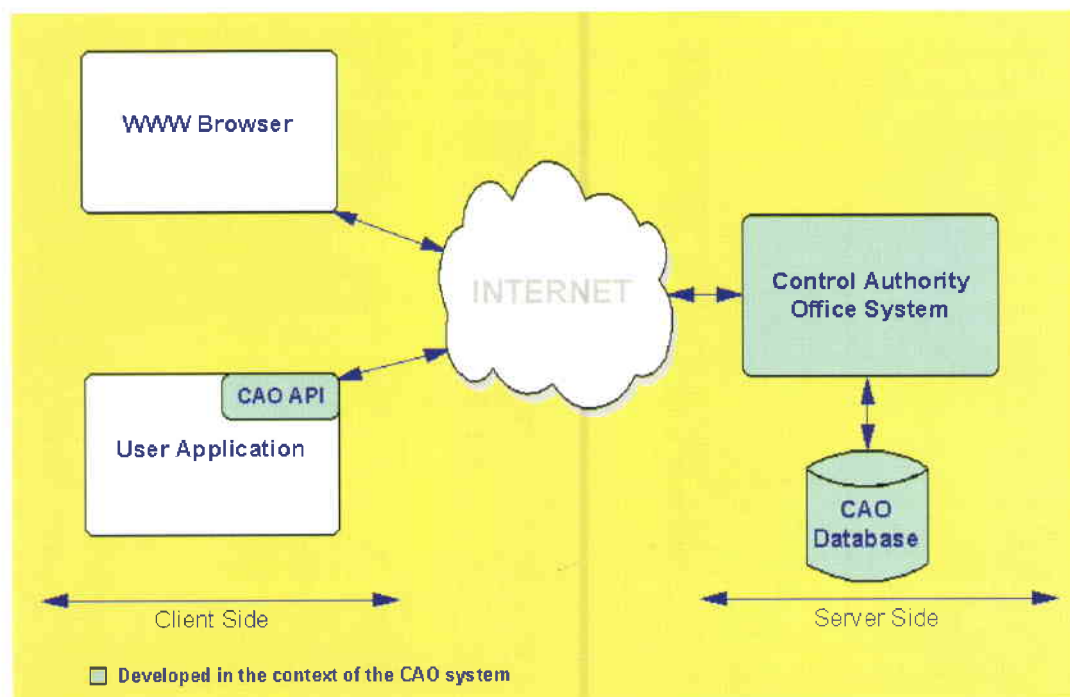


Figure 3. The ESA Control Authority Office system components

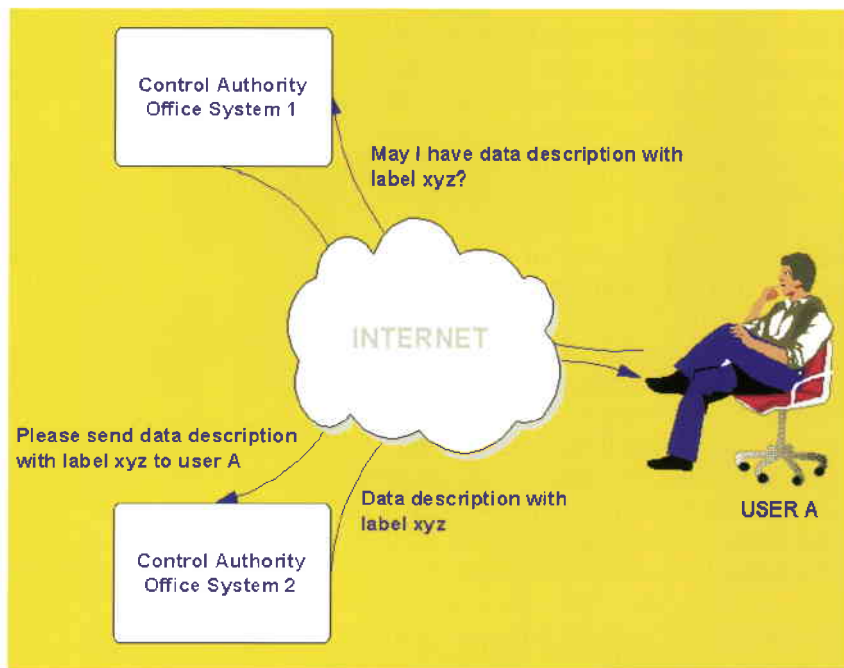


Figure 4. The concept of inter-networked Control Authority Office systems

installation. The concept of having all CAO systems intercommunicating is shown in Figure 4.

Conclusion

This article has explained how greater use of the Internet could be exploited to cover some

of the day-to-day needs of the users of space mission data. The appropriate balance between on-line and off-line data delivery services needs to be established based on the requirement drivers of the particular mission. This is a critical design decision in that it severely influences the data delivery performance and cost of any ground segment.

Unfortunately, no standard is currently imposed for the transfer of mission data to the user community via the on-line and off-line services. In this context, the SFDU mechanism would seem appropriate. Also, considering the services required from the DDS for several recent missions, it would seem that a consistent generalisation effort is possible and that the DDS could be a good candidate.

On the data description side, the ESA CAO system is already available, and its use for future missions therefore has a minimal cost impact.

Those readers interested in obtaining a copy of the ESA CAO system and CAO API software are invited to contact the author of this article.

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Introduction

It is claimed that organisations are not becoming more labour-intensive, material-intensive or capital-intensive, but rather more knowledge-intensive. Despite this, many of today's best-managed organisations remain negligent in administering and leveraging what

referred to as the 'corporate memory', include databases, documents, policies and procedures (i.e. 'explicit' knowledge), as well as previously unarticulated experience and expertise resident in individual workers' brains (i.e. 'tacit' knowledge). Knowledge management thus aims at leveraging the ability of the capable, responsible, autonomous individual to act quickly and effectively.

The Agency needs rapid and convenient access to the data it possesses in order to efficiently reuse it and learn from it. Such data, which can be organised into information and thence transformed into knowledge, resides in many types of documents, databases, cabinet folders and files, as well as in the heads of individuals. Several studies in ESA are looking at ways to prepare the ground for greatly improved management of the Agency's knowledge and to define the required information-technology infrastructure.

One of the policies which is to underpin the overall review of the evolution of the Agency is a 'science and technological policy aimed at improving human knowledge and stimulating economic development' (ESA Council Document (97)56). Knowledge — human capital or intellectual assets — is increasingly being viewed as one of the prime movers in any innovative or technology R&D programme and as one that provides competitive advantage. As the major driving force behind European space activities, ESA has acquired a vast amount of extremely valuable knowledge over the years in all areas of space research. Capturing, unlocking and sharing this unique knowledge, i.e. the reuse of existing intellectual assets, might be the strategy which could simultaneously reduce costs and 'time-to-market' and thereby help make the Agency's projects faster and cheaper. Furthermore, making such knowledge available in a more convenient and structured manner to industry, research institutions, national space agencies and other partners would constitute a valuable return on their investment for ESA's Member States. Management of the Agency's knowledge has also been identified in the ESA Information Systems Master Plan as having a high potential for increasing the Agency's collective efficiency.

is almost certainly their most valuable asset: knowledge. Effective Knowledge Management (KM) is fast becoming a very important strategic issue for both profit-oriented organisations competing in the market place, and non-profit organisations 'competing' against decreasing budgets, decreasing time lines and increasing effectiveness requirements. As a result, the last few years have seen a number of efforts addressing the problem of managing organisational knowledge, in theory and practice, under the umbrella concept of knowledge management.

Knowledge Management is a discipline that promotes an integrated approach to identifying, managing, sharing, and leveraging all of an enterprise's knowledge and information assets, by continuously employing a set of policies, organisational structures, procedures, applications and technologies. These knowledge and information assets, often

* Siemens, Austria

It is becoming increasingly apparent that the Agency's explicit and implicit knowledge created in one area may potentially be needed and used in other parts of the organisation. Thus the accumulation and sharing of knowledge, wisdom, experience and insights would give ESA a powerful base with which to support its work. The problem is capturing it and distributing it for suitable reuse. Also, tacit knowledge is lost and wasted the moment employees leave the Agency, and it is likely that a vast amount of the explicit knowledge that is in all kinds of formats, media and locations is essentially 'lost' because it is mis-filed or because it is neither known about nor accessible by others who may be potential users.

patents or innovation for creating new products).

As yet, no universal 'best practices' and no single technology or best approach for KM have emerged, which is not surprising given the relative youth of the field and the fact that today's KM efforts differ widely in scope and objectives. In fact, four main types of projects can currently be identified in real-world KM efforts.

One type of project aims at providing value-added knowledge repositories. The goal is to capture knowledge, typically from documents with 'knowledge' embedded in them - memos, reports, articles, presentations, and so on - and



Corporate knowledge management

Traditionally, information has been highly structured and stored primarily in data-processing and information-retrieval systems. KM differs from these information engineering approaches in that it aims at providing access not only to large-grained relatively unstructured information, but also to the people who create and use it. KM thus emphasises inter-personal communication over the mere capture and storage of knowledge. More importantly, KM also differs from traditional information management approaches in that tacit knowledge sources, i.e. an organisation's intellectual assets or capital, are a prime target of the knowledge-management efforts.

Central to the theory of KM is the conceptualisation of knowledge as a superior element in a value-chain, including data, information, knowledge, and sometimes even wisdom, and the conceptualisation of knowledge management as a process of refinement, leveraging data and information to the more valuable level of knowledge. This value-added hierarchy is based on a perception of value either in terms of applicability to problem-solving and decision-making (knowledge is that which enables action), or in terms of the asset's value on the balance sheet (capitalising knowledge resources, such as

store them in a repository where they can be easily retrieved. Another, less-structured, form of 'embedded knowledge' can be found in topical discussion lists and bulletin boards. This approach also entails the important process of capturing and representing the content of people's minds, such as tips, tricks and insights related to a particular topic. Typical enabling technologies in this context are data warehouses containing such value-added information as 'lessons learned'.

While capturing knowledge is the objective of the knowledge repository, another type of project focuses on providing access to knowledge or facilitating its transfer among individuals. These projects recognise that finding the person with the knowledge one needs, and then successfully transferring it from one person to another, is a difficult process. The efforts in this category are therefore focused on connectivity, access, and transfer, and the technology enabler often includes Yellow-Page-type (YP) 'road maps' to the tacit and explicit resources of the organisation, or groupware for supporting the communication between individuals.

A third type of KM project involves attempts to establish an environment conducive to more effective knowledge creation, transfer and use.

Projects in this category typically aim at building awareness and cultural receptivity to knowledge, changing the behaviour associated with, for example, knowledge sharing, and improving the KM process itself.

A fourth type of project focuses on managing knowledge as an asset. One way this is being done is by treating knowledge like any other asset on the balance sheet. The Swedish insurance giant Skandia, for example, makes an internal audit of its 'intellectual capital' every year and includes this in its Annual Report. Another approach to knowledge asset management is to focus on managing specific knowledge-intensive assets more effectively to improve their return. An example is Dow Chemical's KM effort, which reportedly saved \$40 million in its first year through better capitalisation on the company's patents.

Knowledge management enablers and barriers

Successful knowledge management, just like any management practice, requires a set of supporting organisational conditions. One enabler is the technology needed to provide enterprise-wide delivery, distribution, and integration of digitally encoded content, and support for the tacit knowledge transfer and sharing that take place in communication and collaboration. However, IT is only one of several enablers or factors to be considered; others include corporate culture, leadership and measurement.

Since the cultural traits needed for KM efforts are often at odds with the existing reality of hierarchical and conservative organisations, it may be necessary to actively change the organisation's culture. For example, since tacit knowledge is only accessible if the human is ready, willing and able to share it, one needs a corporate culture that promotes knowledge-sharing in a climate of trust and openness.

The leadership enabler consists of the will and decision-making required from top management to promote and support the KM effort as a top-level strategic goal of the enterprise, with individuals hired and compensated for their measurable contribution to the development of organisational knowledge. Furthermore, management cycles require self-corrective action and must therefore be able to monitor and measure results. One obvious measurement activity is to link KM efforts to financial results.

There are, of course, several barriers and stumbling blocks which can make the uptake of a corporate KM effort difficult. These are

largely political and cultural rather than technological, with internal political conflicts and power struggles often inhibiting knowledge sharing among members of the same enterprise. Also, if individuals feel they can get ahead in their organisation by hoarding knowledge, the necessary cultural change will be difficult to implement. Misconceptions about the real issues, value and approaches of KM may also prove an obstacle. In particular, KM is often confused with document management, and the fact that most knowledge circulating in an organisation is never captured or documented is overlooked.

Problems related to the technology enabler are not restricted to technical issues, but also involve the way in which the technology infrastructure of an organisation evolves. In particular, a lack of coordination of IT-related efforts can result in incompatible 'information islands', whereby data and information that should be shared (i.e. corporate data) is not available to users across the various functional domains of the organisation. It must therefore be recognised that KM is a corporate undertaking and that a top-down approach to coordinating the various IT developments is required, in the form of defining and imposing policies for standardisation and interoperability among applications and content.

The importance of KM to ESA

Two issues of critical importance to an organisation like ESA in a time of downsizing and restructuring are increasing the efficiency and effectiveness of their staff, and making the very best use of their knowledge, experience and talents. An increasing amount of the work performed internally is knowledge and information intensive, and by focusing on knowledge sharing the Agency's highly skilled staff will not only gain ready access to knowledge and experience in their own domain, but also to knowledge and tools elsewhere in ESA that they previously may not have been aware of. Developing a better corporate memory for the Agency and actively managing its existing knowledge would therefore: enhance knowledge transfer and use; foster greater cooperation; stimulate creativity and innovation; help in managing expertise; reduce unnecessary duplication and wasting of resources; permit better monitoring and control; and generally increase efficiency.

In the context of downsizing, KM can help to prevent knowledge loss resulting from staff leaving the organisation and taking their knowledge and expertise with them. It also has an important role to play in failure management. System or subsystem failures are one of the

largest sources of unforeseen costs in aerospace projects, and they can often be traced back to poor decision-making under cost/schedule pressures. The underlying cause for such human error is often lack of knowledge, or the lack of immediate access to knowledge. In this same context, KM can also provide some protection against the repetition of previous mistakes.

The ESA infrastructure for KM

In some respects, ESA has always had a 'corporate memory'. The thousands of documents that have been produced with respect to the many programmes and projects worked on have been kept and archived, and many of the staff involved in these projects who have accumulated a vast amount of experience and knowledge are still with the Agency. The problem is that the material itself and the knowledge that the staff have accumulated is presently not in a convenient form for consultation, analysis and reuse. The Agency therefore needs to create a seamless, value-added IT environment which builds upon available knowledge and lessons learned, supports existing platforms and applications and enables users of the knowledge environment to access a 'one-stop store' of information and data, both historical and current. The main IT objective therefore becomes one of providing an ESA-wide information systems architecture of compatible applications that can integrate and deliver this content.

This environment must in essence deliver three main services. Firstly, it must provide repositories of value-added information, applicable to problem-solving and decision-making. Second, it must provide information and knowledge 'road-maps', enabling access to all the existing and previously isolated resources in the organisation, including the accumulated knowledge and experience of individuals. Finally, it must provide the necessary support for tacit knowledge sharing. The core components for a KM application environment able to meet these goals are: value-added repositories in the form of 'data warehouses', meta-databases such as Yellow-Page-type directories and meta-servers, and finally groupware applications such as Lotus Notes. These elements are further explained in the accompanying panel.

Developing the application environment

In order to arrive at the integrated application environment providing access to the information and knowledge sources of the Agency, the YP and value-added applications that are key to KM must be developed and

populated. In addition, a set of policies and procedures related to the use and evolution of the resulting information spaces must be defined and institutionalised.

The first activity that must be tackled is a detailed survey of all existing knowledge and information resources, tacit and explicit, within the Agency. The result of this activity, often referred to as the Enterprise Knowledge Architecture (EKA), is an important first step

Value-Added Repositories and Data Warehouses

A 'data warehouse' is a repository of operational data from many sources which has been extracted, filtered, consolidated, summarised, formatted and optimised for presentation in ways conducive to analytical thinking. The purpose of the data warehouse is to provide decision-makers, such as scientists, engineers, or managers, with timely information for making critical decisions. Its content should include lessons learned and salient knowledge or understanding gained by experience. The experience may be positive, as in a successful test or mission, or negative, as in the case of a mishap or failure.

Meta-databases: Yellow-Page Directories and Meta-Servers

Whereas data warehouses are repositories for value-added content, the role of meta-databases in the KM context is rather to provide information about, and a common entry-point to the heterogeneous knowledge and information repositories of an organisation. They therefore serve as detailed directories to what is available where, by providing descriptions of data elements and incorporating related contextual information.

Meta-databases for KM are of two types, Yellow-Page-type (YP) directories and meta-servers. The YP directory is in essence a navigational guide to the organisation's information and knowledge resources, and is frequently used to create exhaustive 'road-maps' to all of those resources. Given that the capture of tacit knowledge can be hard and costly, YP directories often point to individual people as important sources of knowledge.

Whereas a YP application provides a directory of heterogeneous resources, the meta-server provides in addition a common interface for access to the contents of these repositories. Its distinguishing characteristic is that it must provide interoperability among the heterogeneous applications it encompasses, at the Application Programming Interface (API), syntax and semantic levels.

Groupware

While the above systems and functionalities focus on providing enterprise-wide access to and integration of knowledge and information repositories, groupware is important to the KM objective of supporting tacit knowledge sharing and transfer within the organisation. The role of groupware is to assist groups in communicating, in collaborating, and in coordinating their activities, whether via phone, e-mail, discussion databases, bulletin boards, voice mail, etc.

Lotus Notes is a typical component of many KM-initiatives reported in case-studies. Access to knowledge repositories can be provided through the Notes databases, communication and limited collaboration provided through the messaging facility and associated databases and add-ons, and the potential for resource directories in the form of Yellow-Pages is supported by the distributed database architecture.

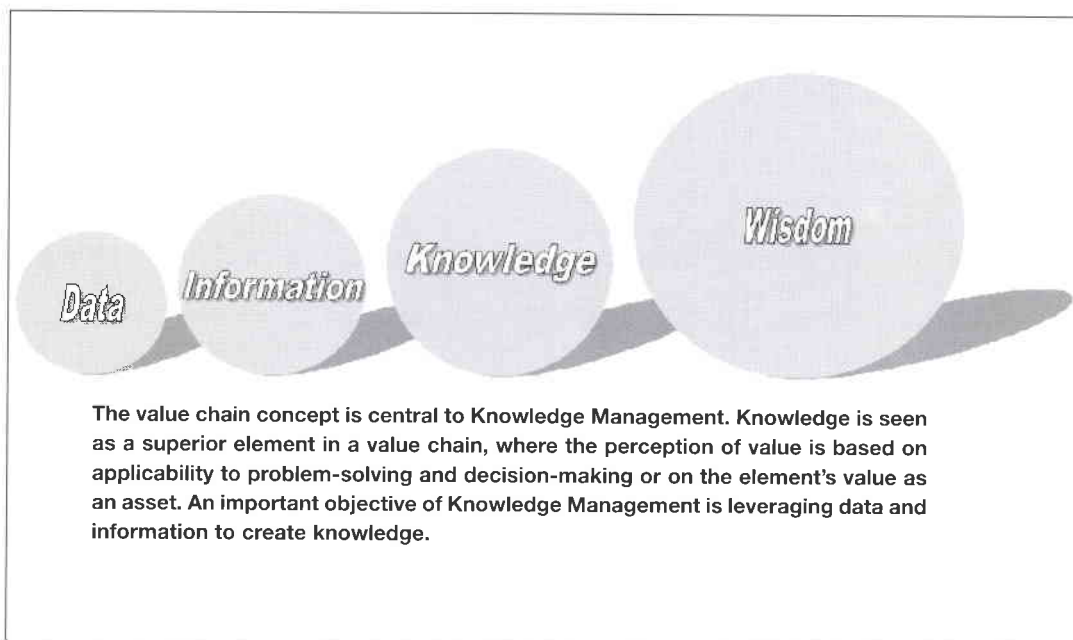
because the application environment depends on it: important content will go through a process of refinement and populate the value-added repositories, other elements will simply be referenced by the YP directories. The explicit information resources must be identified with a survey of at least the machine-readable databases (e.g. full text, factual, numeric, bibliographical, directory, multimedia etc.); printed material (e.g. the company library, archives, journals, grey literature, etc.); audio/visual collections (e.g. photos, videotapes, recordings etc.) and the like.

Identifying and capturing the accumulated tacit resources of the Agency may entail much more

procedures aimed at enabling those repositories to 'forget' are crucial in order to make sure that only the latest information is available and that obsolete information is removed, since a repository with outdated content would quickly lose its practical value.

Current KM-related efforts within ESA

The activities outlined below, conducted at ESRIN and ESTEC, can all be seen as providing important inputs for identifying and setting up an appropriate KM application environment for the Agency in the coming years. Several knowledge-based studies are also currently in progress at ESOC.



complex and time-consuming knowledge elicitation methods, such as interviews with senior and key staff. Clearly, detailed knowledge elicitation, which is hard enough with one expert in one narrow domain, is probably not feasible on an Agency-wide scale, but detailed representations of tacit knowledge can also be substituted by competency-maps, providing simple pointers to the individuals who possess key knowledge.

It is also important in developing the application environment to ascertain just how the identified and captured content might be most efficiently used for problem-solving, decision-making, etc. and hence what kinds of output might be required. It will also be necessary to address such technical issues as: the problems of data and knowledge validation, the projected growth of the database, the updating of its contents, legal aspects such as copyright, company confidentiality, proprietary data, and the security aspects. Given the rapid growth to be expected in the Agency's KM repositories,

Knowledge Data-Warehouse Study

A small pilot study carried out by Moreton Hall Associates for the Systems Studies Division at ESTEC at the beginning of 1997 was helpful in defining many of the kinds of documents and databases that the Agency possesses and in attempting to categorise the kinds of information and data embedded in them. It also highlighted some of the problems of knowledge and decision capture and many of the issues surrounding corporate memory development and the culture/environment required to foster and sustain such a concept.

Based on the outcome of the Moreton Hall study, a more ambitious undertaking by the Systems Studies Division aimed at laying the foundations for developing a concept for a data warehouse that could be used by ESA staff, industry and the national space agencies is in the advanced definition stage. The new effort does not seek to duplicate existing activities, but rather to complement them by identifying other types of data that could form part of an

overall ESA knowledge-management and corporate-memory strategy.

The data warehouse could comprise different types of information and data from a variety of sources: published documents, grey literature, tacit knowledge, lessons learned, experience acquired, decisions taken, etc. It could also include information on pertinent system/subsystem equipment for projects, e.g. components, power supplies, propulsion systems, and what testing they have been subjected to, previous in-flight performance data, etc. The grey literature might include such documents as project specs., change records, design and test review results, enquiry board results, etc.

A further goal is to examine the methodology and procedures for extracting, structuring and searching the data, as well as exporting it to other systems.

Ultimately, the appropriate tools for ESA will depend on the type of data to be extracted and stored, the types of questions likely to be posed, the types of analyses expected to be performed, and the degree of compatibility required within ESA's data-warehouse environment (in particular the Lessons Learned Information System being constructed by ESTEC's Product Assurance and Safety Department) and other relevant systems or databases (e.g. those of the Cost-Analysis Division at ESTEC).

Corporate Knowledge Management Study

ESRIN's Management Information Systems Division, together with Siemens Austria, has a study in progress entitled 'Corporate Knowledge Management Study', as a follow-up to an earlier ESRIN study on 'Generation of Hyperlinks for Large Collections of Documents'.

Phase-1 of the latest project focused on understanding the real issues in the young field of corporate-knowledge management, and on clarifying the role and potential, but also the limitations, of information technology. Eighteen real-world KM efforts were analysed (some originating in the aerospace sector) to understand both the success factors and barriers. This phase also served to identify which tools and technologies are ideally required for knowledge management, what is required in terms of IT infrastructure, as well as listing those elements of an IT strategy critical to a successful KM technology implementation.

Phase-2 of this study will result in a detailed proposal for the application of information

technology to an existing ESA knowledge cycle, outlining the methodology, infrastructure and requirements by November 1997. The prototype's implementation is expected to be finalised by December 1998. A knowledge cycle related to the Agency's Technology Research & Development (TRD) activities is currently being targeted.

ESA Lessons Learned System

After the successful implementation of its ESA Alert System, which facilitates the urgent exchange of information to prevent the repetition of identified spacecraft failures, the ESTEC's Product Assurance and Safety Department has undertaken the development of a system with a broader perspective. This system, known as ELLS (ESA Lessons Learned System), is intended to extract the useful lessons learned (both positive and negative) from past space experience and make them available to those who may benefit from such knowledge for future projects. In particular, ELLS is intended to:

- consolidate and preserve ESA corporate knowledge
- promote continuous improvements in processes, methods and techniques
- inform staff in ESA, the national space agencies and European space industry of the lessons learned
- provide for suitable interfaces with other lessons learned systems.

Sources of information within ESA include the project and support staff, Alerts, Audits, project documentation and ESA publications. External sources can include staff of and documentation from other space agencies and industry. Consistent sharing of lessons learned should enable managers to recognise and respond to both good practices and potential dangers. The expected beneficiaries of the system include the Agency's project and functional-support staff, the national space agencies in Europe, as well as the industrial contractors involved in ESA projects. The latter have already shown great interest in providing data based on their own experience and in exploiting the system for their own needs.

A study for a pilot implementation of ELLS is currently being conducted, covering the definition of the process for the collection, validation and exploitation of lessons learned. It also covers the development of a tool to make the information available to users via the World Wide Web, as well as to support ESA's administration of the system.

At present, the User Requirement Document for the ELLS computer-based tool is being

finalised. The software application and the operational procedure are expected to be ready by the beginning of 1998.

In-Flight Experience Study

Another activity that can be classed under the general heading of corporate memory or KM is a study to be carried out as part of the General Studies Programme on the topic of feedback from satellite in-flight experience to satellite design and margin concepts. European space industry already has a sufficiently long list of successful scientific, applications and commercial satellites to its credit from which much experience and many lessons learned could be extracted and put to good use in future satellite design efforts in order to be able to compete even more effectively on the world market.

This study, led by the Systems Studies Division at ESTEC, is presently in the early definition stage. Part of the task could be to build up an 'as-flown' database on as many European satellites as possible, containing such data as in-orbit performances, in-flight anomalies, trend analyses of critical parameters, etc. Such a database would be a useful addition to ESA's corporate memory and one that could potentially yield a high return for European space industry if constructed and used in the correct manner.

Conclusion

Knowledge management is a discipline that promotes an integrated approach to identifying, managing, sharing and leveraging all of an enterprise's knowledge and information assets. These assets, often referred to as the 'corporate memory', include explicit resources such as databases and documents, as well as previously unarticulated 'tacit' experience and expertise resident in individual workers. It is generally accepted that successful KM efforts require certain organisational conditions, related to culture and to leadership as well as to information technology.

KM has been identified as an issue of considerable importance in many forward-thinking organisations, and ESA too can benefit greatly by adopting such a strategy. This article has given a brief introduction to some of the current activities within the Agency that are focusing on providing the technology needed for managing its corporate memory. These efforts should eventually lead to the building of several pilot applications involving Yellow-Page-type directories and value-added space-knowledge repositories in the form of Data Warehouses. Such a knowledge-management environment of accumulated wisdom, insights

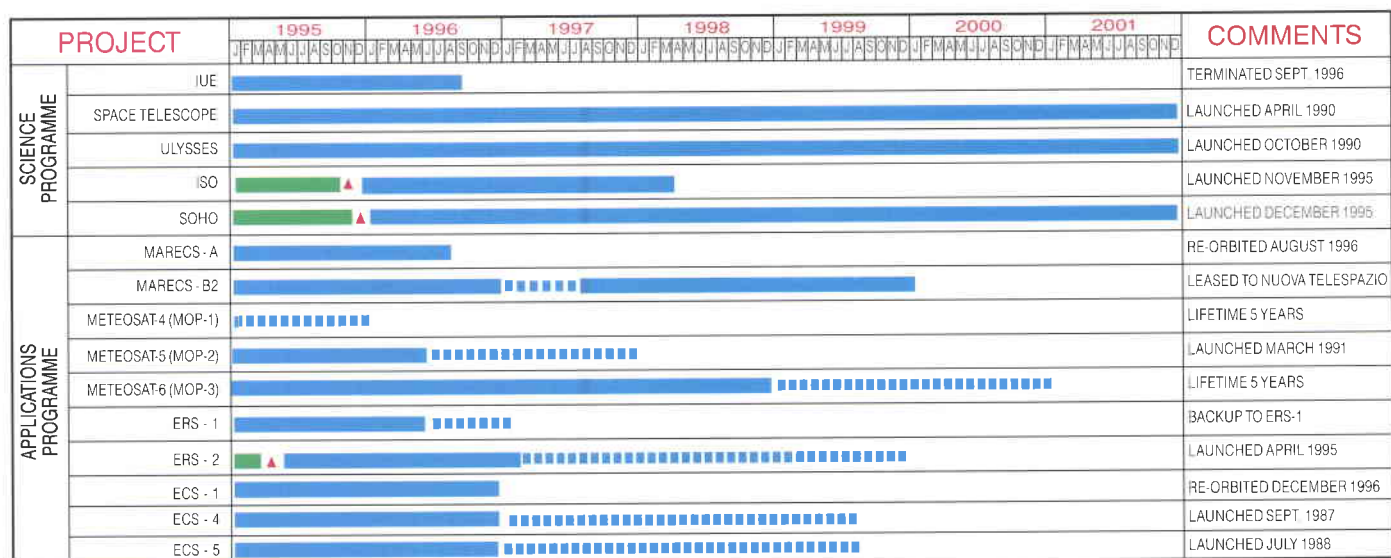
and experience would provide the core of an ESA corporate memory and would give the Agency, as well as European space industry, an extremely powerful tool with which to support its future and enhance its competitiveness. It is clear, however, that reaching the goal of creating such a KM environment requires significant coordination and standardisation of all of the corporate-level IT efforts throughout the Agency.

esa

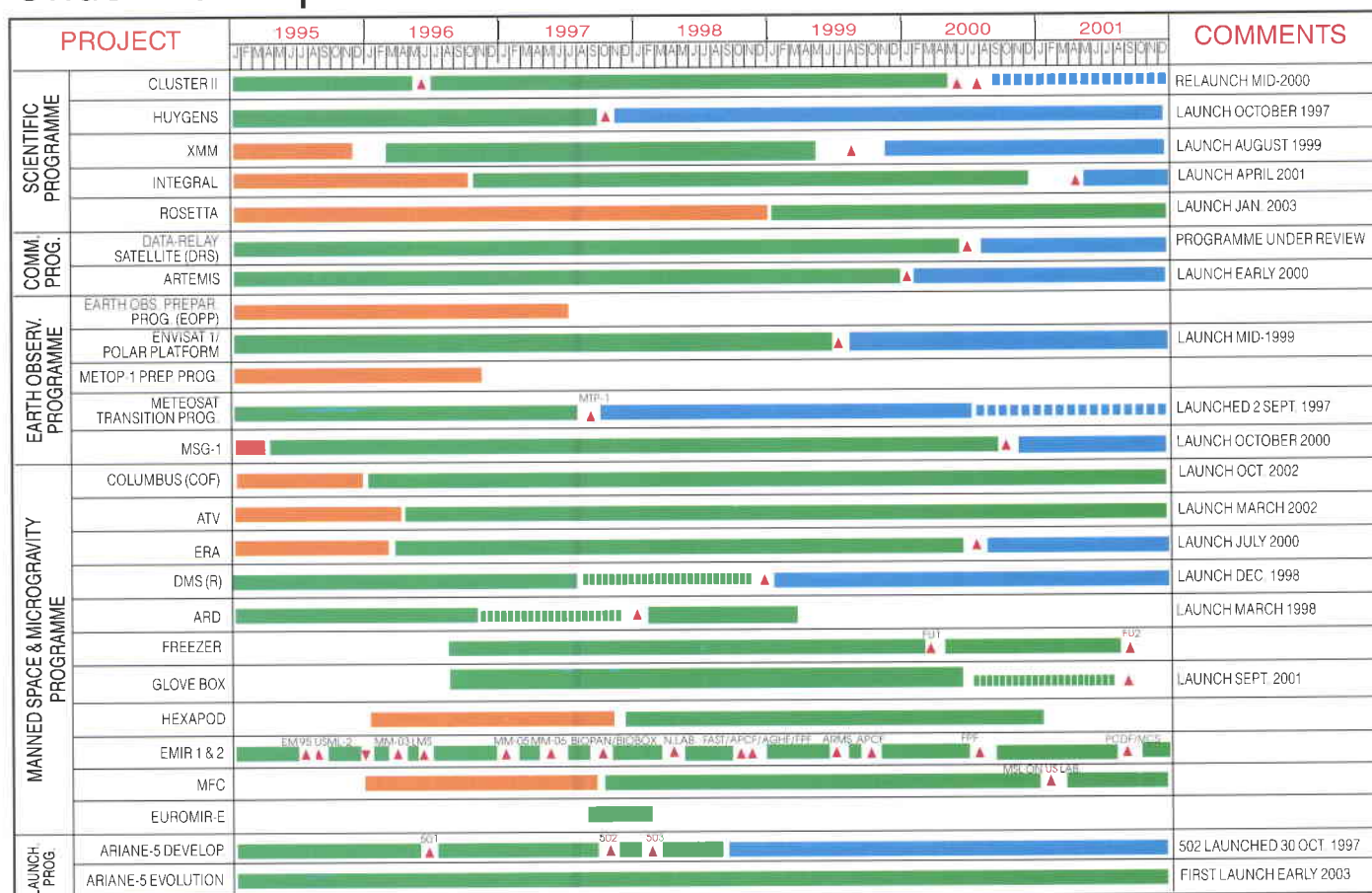
Programmes under Development and Operations

Programmes en cours de réalisation et d'exploitation

In Orbit / En orbite



Under Development / En cours de réalisation



■ DEFINITION PHASE

■ MAIN DEVELOPMENT PHASE

▲ LAUNCH/READY FOR LAUNCH

■ OPERATIONS

■ ADDITIONAL LIFE POSSIBLE

▼ RETRIEVAL ■ STORAGE

Integral

La Revue de conception détaillée, qui comprenait également des représentants de la NASA et de la RKA, a été menée à bien le 6 juin chez le maître d'oeuvre Alenia Spazio à Turin en Italie.

Les principales conclusions auxquelles la commission d'examen est parvenue sont les suivantes:

- la régulation thermique au niveau des batteries du satellite et de l'ensemble détecteur de l'imageur au cours de la phase de croisière requiert une attention spéciale;
- les opérations de lancement à Baïkonour ne sont pas encore définies et doivent par conséquent être examinées en toute priorité.

Le segment sol avec ses nombreux éléments (stations terriennes, Centre d'opérations de la mission, Centre d'opérations scientifiques Integral et Centre des données scientifiques Integral) demande encore un examen approfondi. La commission s'est mise d'accord pour consacrer une revue spéciale au segment sol englobant tous les éléments ci-dessus ainsi que les opérations de vol prévues. Elle a pris bonne note des progrès accomplis dans la définition de l'interface technique entre Integral et le lanceur Proton.

Enfin la commission a conclu que les problèmes rencontrés paraissent bien circonscrits et que les objectifs de la Revue de conception détaillée ont été atteints.

XMM

L'intégration du modèle structurel et thermique du véhicule spatial est terminée et une série d'essais a été menée à bon terme chez Dornier (D). On prépare actuellement le satellite en vue de son expédition à l'ESTEC (Pays-Bas), où la campagne d'essais d'ambiance commencera fin septembre et se prolongera jusqu'au début de 1998. En parallèle, l'intégration du modèle électrique progresse de façon satisfaisante. Fin août, après des essais concluants menés chez Matra Marconi Space (F), le sous-système de commande d'orientation et de correction d'orbite (AOCS) a été livré chez Dornier où il est actuellement intégré aux

panneaux d'équipements de la maquette du module de servitude.

Alors que les premiers équipements de vol sont en voie d'achèvement, les préparatifs de la revue critique de conception (CDR) au niveau système sont en cours. Cette revue aura lieu en septembre et octobre à l'ESTEC et aura pour objectif d'évaluer si le système est apte à être intégré au modèle de vol du satellite.

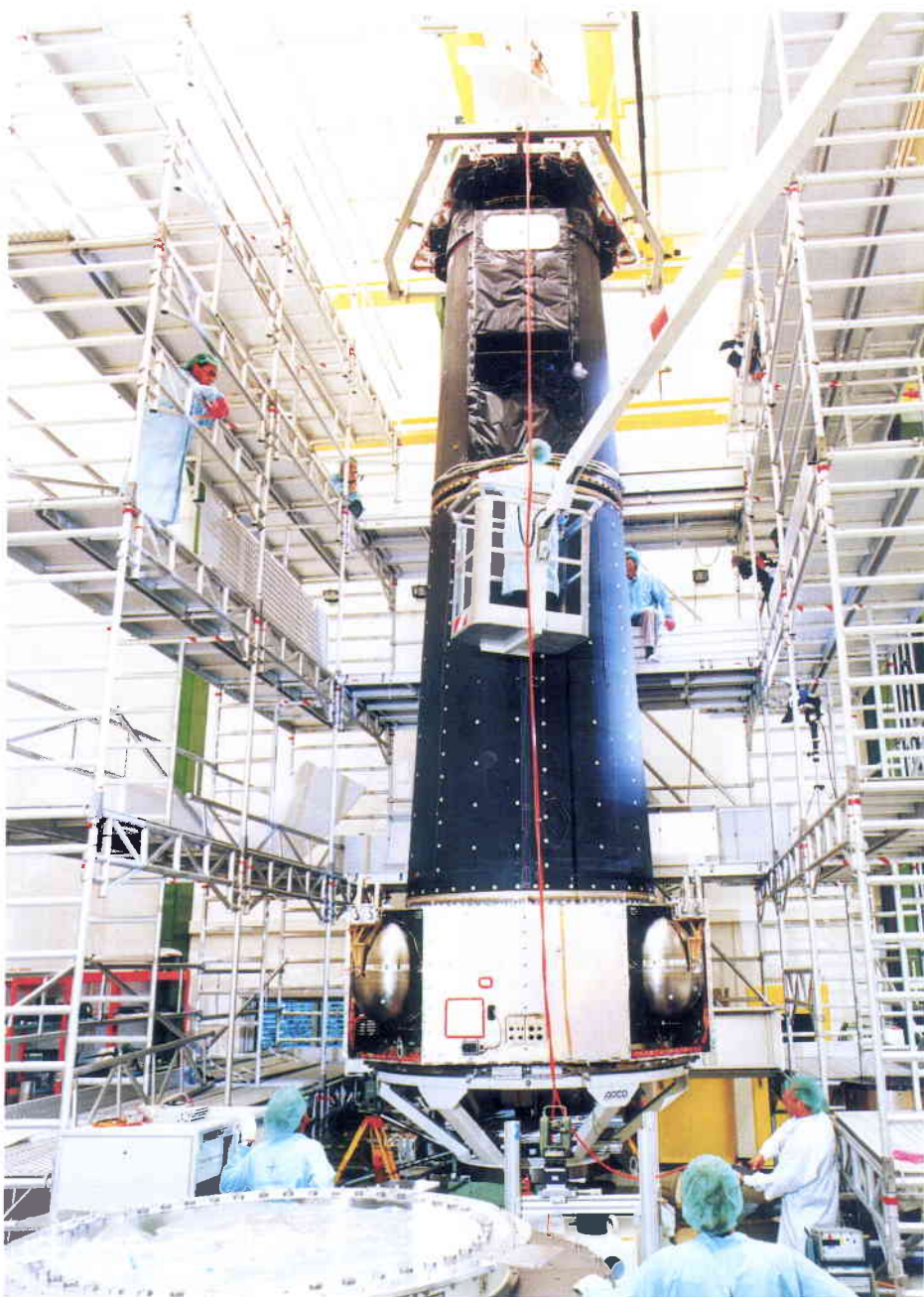
Media Lario (I) a livré un troisième module de vol qui, au terme des premiers essais optiques, devrait se comporter nettement mieux que ce que prévoient les spécifications. Les essais sur ce module de miroir se poursuivent chez CSL (B) tandis que Media Lario travaille sur le module de vol de réserve.

Integration of the XMM spacecraft in progress at DASA/Dornier (D)

Intégration du satellite XMM chez DASA/Dornier (D)

La campagne d'étalonnage d'un module de vol de miroir, des réseaux et des détecteurs de vol de l'expérience RGS s'est terminée dans l'installation PANTER de l'Institut Max-Planck (D). La prochaine campagne de ce type portera sur la caméra EPIC (MOS) et s'achèvera fin novembre.

Les modèles d'identification des expériences ont été livrés à Dornier pour



Integral

The Detailed Design Review (DDR) was successfully completed on 6 June at Alenia Spazio (I), the prime contractor, in Turin. The DDR Board also included representatives from NASA and from RKA.

The major findings of the Board were as follows:

- the thermal control during the coast phase for the spacecraft batteries and the Imager detector assembly requires special attention
- the launch operations at Baikonur are not yet defined and this aspect needs to be pursued with a high priority.

The ground segment, with its many elements — ground stations, Mission Operations Centre, Integral Science Operations Centre and Integral Science Data Centre — still needs further scrutiny. The Board was in agreement that a dedicated review of the ground segment, including all of these elements and the planned flight operations, should be conducted. It noted the good progress made in defining the technical interface between Integral and the Proton launcher.

The Board concluded that the problems identified appeared to be under control and that the DDR's objectives had been met.

XMM

Integration of the structural and thermal model of the spacecraft is complete and a series of tests have been successfully conducted at DASA/Dornier (D). The satellite is currently being prepared for shipment to ESTEC (NL), where the environmental test campaign will start in late September and last into early 1998. In parallel, the integration of the electrical model is progressing well. In late August, after successful tests at Matra Marconi Space (F), the attitude and orbit control subsystem (AOCS) equipment was delivered to Dornier, where it is currently being integrated onto the equipment panels of the service-module mock-up.

Whilst the first flight-equipment units are approaching completion, preparations for the system-level Critical Design Review (CDR) are underway. This review will be held during September and October at

ESTEC in Noordwijk, and will assess system readiness for flight-satellite integration.

Media Lario (I) has delivered a third flight module which, according to the first optical tests, promises to perform significantly better than specification. While tests at CSL (B) on this mirror module continue, Media Lario is working on the flight-spare model.

The calibration campaign that involved a flight mirror module together with the RGS experiment flight detectors and gratings in the Max-Planck Institute's PANTER facility (D) has been completed. The next such campaign will involve the EPIC (MOS) camera and will last until late November.

The engineering models of the experiments have been delivered to Dornier for integration into the spacecraft engineering model. Flight-model production is proceeding well. The optical elements, as mentioned above, are being used in the PANTER calibration campaign.

Work on ground-segment development has progressed according to plan and the contract negotiations for the software development have been successfully concluded with Logica (UK).

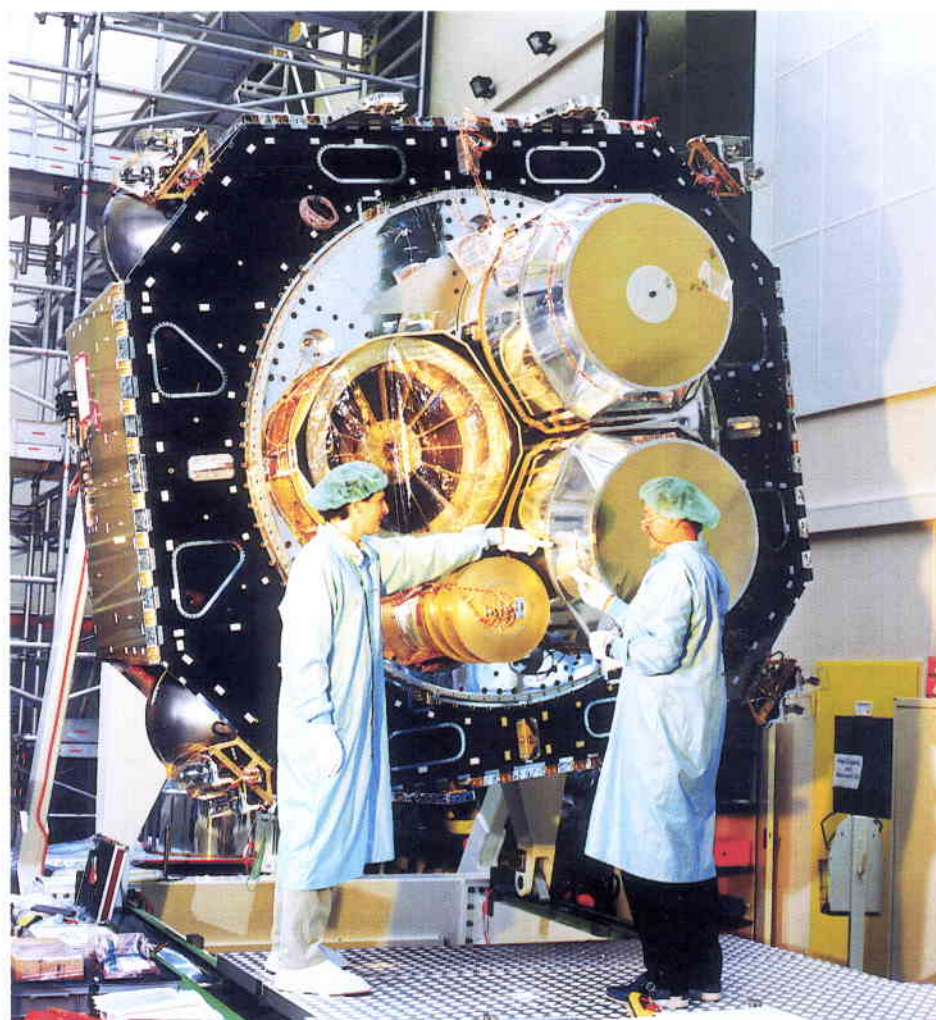
Following the reaching of agreement concerning the electrical and mechanical interfaces between XMM and its Ariane-5 launch vehicle, the Interface Control Document has been completed and signed off. The interfacing provides for fully redundant umbilical connections and the purging of the most sensitive areas of the satellite with clean air and nitrogen until the last moment before lift-off.

Rosetta

The Phase-B industrial activities have

Integration of XMM's X-ray baffle onto the mirror support platform at DASA/Dornier (D)

Intégration de l'écran de rayons X sur la plateforme du miroir de XMM chez DASA/Dornier (D)



être intégrés au modèle d'identification du véhicule spatial. La fabrication du modèle de vol se poursuit de façon satisfaisante. Les éléments optiques, comme mentionnés ci-dessus, sont utilisés dans le cadre de la campagne d'étalonnage PANTER.

Les travaux de développement du secteur sol se sont poursuivis conformément au calendrier et les négociations portant sur le contrat de développement du logiciel ont été menées à bon terme avec Logica (R-U).

Après l'accord sur les interfaces électriques et mécaniques entre XMM et Ariane 5, le document de contrôle des interfaces a été parachevé et signé. L'ensemble des interfaces constitue des connexions ombilicales totalement redondantes et assure la purge des zones les plus sensibles du satellite avec de l'air propre et de l'azote jusqu'au dernier moment avant le décollage.

Rosetta

Les travaux industriels de la phase B se sont poursuivis; l'accent a été mis sur l'évaluation des offres reçues de l'industrie pour ce qui est de la plate-forme de l'engin spatial et l'avionique qui constituent les deux sous-systèmes les plus importants de Rosetta. Les évaluations ont été menées par l'ESA pour le compte de Dornier.

Le Comité du programme scientifique de l'Agence (SPC) a approuvé la dotation en charge utile de Rosetta. Les parties en cause ont trouvé une solution pour financer l'expérience Rosina. Les activités de conception et de définition de l'instrument sont en cours. Les travaux de définition du secteur sol progressent conformément au plan.

Artemis

Satellite

Au terme des programmes d'essai menés sur les modèles structurel et d'identification du satellite, le modèle de vol concentre maintenant toute l'attention. La structure de vol, entièrement intégrée avec les équipements de propulsion et de régulation thermique, est désormais prête

à recevoir les équipements électriques. Avant que cette opération puisse commencer, un certain nombre de sous-systèmes devront passer l'épreuve des essais de recette; on attend pour cela la livraison d'un petit nombre d'éléments manquants.

Pour améliorer les capacités de fonctionnement de la charge utile de télécommunications pour le service mobile en bande L, il a été décidé d'installer un répéteur qui sera utilisé dans le cadre du système GNSS destiné à augmenter les systèmes de navigation GPS/GLONASS. Les matériels nécessaires à ce répéteur seront développés parallèlement aux essais 'système' du satellite Artemis puis intégrés au satellite à la fin du programme d'essai.

Terminal Silex LEO

Spot-4, y compris le terminal Silex LEO qui lui a été intégré au début de l'année, a terminé son programme d'essais d'ambiance. Une série d'essais de préparation à l'exploitation est en cours d'exécution; le satellite sera ensuite expédié, en janvier, sur le site de lancement.

EOPP

Stratégie future

Le groupe de travail stratégique sur l'observation de la Terre qui a été chargé de préparer les débats de la prochaine session du Conseil au niveau ministériel en 1998 ainsi que le groupe de travail industriel ad hoc ont poursuivi leurs travaux. Les résultats préliminaires seront présentés dans le cadre d'un atelier avec l'industrie qui se tiendra les 23 et 24 octobre à l'ESTEC; on y donnera aussi les réponses à un questionnaire largement diffusé auprès des industriels.

Programmes futurs

Les onze Etats membres qui participent au programme EOPP ayant décidé, exceptionnellement, de lancer l'extension 2 avec un niveau de souscription de 46,21%, les travaux liés aux missions potentielles d'exploration et de surveillance de la Terre ont été engagés. On attend toujours que les Etats qui n'ont pas encore souscrit fassent part de leurs intentions. A moins d'une augmentation substantielle des souscriptions, le programme de travail devra être révisé.

Campagnes

La première d'une nouvelle série de campagnes est en cours de préparation. Dénommée CLARE 1998, elle s'appuiera sur les travaux en cours sur le site radar de Chibolton (R-U) et étudiera les caractéristiques des nuages au moyen d'observations par satellite, par radar et par lidar aéroportés et aussi d'observations in situ.

Plate-forme polaire/Envisat

Système Envisat-1

A la suite des recommandations de la revue critique de conception du système 'Mission Envisat (CDR-EMS)', les activités au niveau système se sont concentrées sur le parachèvement de la documentation relative aux interfaces et sur la préparation des vérifications globales du secteur sol (GSOV).

Le document sur la politique de données, élaboré par le Groupe de travail Politique de données, a été présenté pour approbation au Conseil directeur du programme d'observation de la Terre.

L'avis d'offre de participation relatif à l'exploitation des données scientifiques et à des projets pilote a été préparé et sera diffusé dès qu'il aura été approuvé par les Etats participant au programme.

Un projet du plan des opérations de haut niveau (HLOP) a été préparé et le DOSTAG poursuit ses travaux de revue de ce document.

Plate-forme polaire (PPF)

Les activités relatives à l'intégration du modèle d'identification de la plate-forme polaire ont bien progressé et ont atteint deux objectifs principaux : premièrement, le modèle de vol du module de servitude et le modèle d'identification du module de charge utile ont été assemblés sur le plan électrique et testés sur le plan fonctionnel ; aucun problème grave n'a été relevé, ce qui valide le fonctionnement électrique et fonctionnel d'ensemble du satellite. Deuxièmement, le modèle d'identification de l'instrument MERIS a été intégré et soumis à essais.

Au terme des activités de qualification du modèle structurel du module de la charge utile, celui-ci a été renvoyé chez Matra

continued with the main emphasis on evaluation of the offers received for the platform and the avionics, which are two of Rosetta's major subsystems. The evaluations have been conducted by ESA on behalf of Dornier.

The Agency's Science Programme Committee (SPC) has approved the Rosetta payload complement, and a solution to the problems in funding the Rosina experiment has been found by the parties involved. Instrument design/definition is currently in progress.

The ground-segment definition work is proceeding according to plan.

Artemis

Satellite

Following completion of the test programmes on the structural- and engineering-model satellites, the flight model has become the focus of attention. The flight structure, fully integrated with propulsion and thermal-control hardware, is now ready for the integration of the electrical equipment. Before this can start, acceptance testing of some subsystems must take place and this is awaiting the delivery of a few remaining equipment items.

To improve the mission capabilities of the L-band mobile communications payload, it has been decided to introduce a transponder to be used as part of the Global Navigation Satellite System (GNSS) to augment the GPS/GLONASS navigation systems. The equipment for this transponder will be developed in parallel with the Artemis satellite system testing and integrated with the satellite late in the test programme.

Silex LEO terminal

Spot-4, including the Silex LEO terminal which was integrated with it earlier in the year, has now successfully completed its environmental test programme. A series of operational preparation tests are now underway before the satellite is shipped to the launch site next January.

EOPP

Future strategy

The reflections of the Earth Observation

Strategy Task Force, established to prepare for discussions at the next Council Meeting at Ministerial Level in 1998, have continued, as have those of the Industrial Ad-Hoc Working Group. The preliminary results will be presented to an Industrial Workshop on 23/24 October at ESTEC, along with the outcome of wide (questionnaire-based) consultations with Industry.

Future programmes

Following the agreement by the eleven Participating States to exceptionally initiate EOPP Extension 2 at a 46.21% subscription level, work in support of both potential Earth Explorer Missions and Earth Watch Missions has been initiated. Clarification of the intentions of the 'missing' subscribers is still awaited. Unless there is a significant increase in subscriptions, the work programme will have to be reviewed.

Campaigns

The first of a new series of campaigns is now in preparation. Called CLARE 1998, it will build on ongoing work at the Chilbolton radar site (UK) and will study cloud properties by means of satellite observations, airborne radar and lidar, and in-situ observations.

Polar Platform/Envisat

Envisat-1 system

Following the Envisat Mission System Critical Design Review (EMS-CDR) recommendations, the system activities have focused on the finalisation of the interface documentation and preparation of the Ground Segment Overall Verification (GSOV).

The Data Policy document, elaborated by the Data Policy Task Force, has been submitted to the Earth Observation Programme Board for approval.

The Announcement of Opportunity for scientific data exploitation and pilot projects has been prepared and will be released as soon as it has been approved by the Programme Participants.

A draft of the High-Level Operation Plan (HLOP) has been prepared and review work with the DOSTAG is in progress.

Polar Platform (PPF)

The Polar Platform engineering-model

integration activities have progressed well with two major achievements. Firstly, the Service Module flight model and the Payload Module engineering model have been electrically assembled and functionally tested. No significant problems have been identified, thereby validating the overall satellite electrical and functional operation. Secondly, the MERIS engineering-model instrument has been integrated and tested.

Following completion of the structural-model qualification activities, the Structural Model Payload Module has been returned to Matra Marconi Space (UK), where the structure is undergoing refurbishment to become the flight-model structure. The flight-model harness has been manufactured.

Integration of the flight-model Payload Equipment Bay has been completed and final acceptance tests are being performed at DASA/DSS (D).

Following a recommendation of the EMS-CDR Board, it has been decided to use a Solid-State Recorder (SSR) to replace one of the four tape recorders. The associated adaptation and procurement activities have been initiated.

Envisat-1 payload

The engineering-model programme is nearing completion for most instruments. The test results achieved so far show that performances are well within specification.

The MERIS engineering model has been delivered for integration on the PPF spacecraft as planned, and will be followed closely by the Central Electronic Assembly (CESA) of the ASAR instrument.

In the flight-model programme, a first milestone has been achieved with the delivery by Alenia Spazio (I) of the MWR flight-model instrument at the beginning of August. The MWR is now being assembled in a common structure with DORIS, a CNES-provided Announcement of Opportunity (AO) instrument. Work on the MWR/DORIS complement is planned to be completed by the end of the year.

The manufacture, assembly and testing of the other flight-model instruments is well advanced. The delivery of the last flight-model electronic units is expected to be finalised by mid-September.

Marconi Space (R-U) où la structure est remise en état pour devenir la structure du modèle de vol. Le câblage du modèle de vol a été fabriqué.

L'intégration de la case à équipements de la charge utile du modèle de vol est terminée et les derniers essais de recette sont en cours chez DASA/DSS (D).

Suite à une recommandation de la CDR-EMS, il a été décidé d'utiliser un enregistreur à l'état solide (SSR) pour remplacer l'un des quatre enregistreurs à bande. Les travaux d'adaptation et d'approvisionnement correspondant ont été lancés.

Charge utile d'Envisat-1

Les modèles d'identification de la plupart des instruments sont en voie d'achèvement. Les résultats des essais obtenus jusqu'à présent montrent que les caractéristiques de fonctionnement sont parfaitement conformes aux spécifications.

Le modèle d'identification de l'instrument MERIS a été livré pour être intégré, comme prévu, au véhicule spatial PPF. Il sera suivi de près par l'ensemble électronique central de l'ASAR.

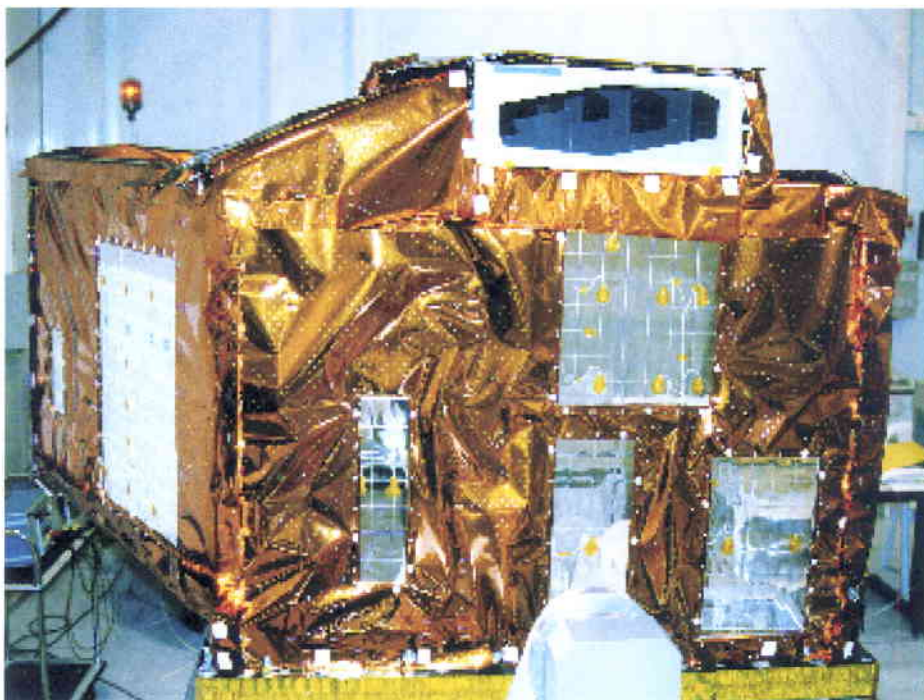
Une première étape a été franchie, début août, dans le programme de modèle de vol avec la livraison par Alenia Spazio du modèle de vol du MWR. Le MWR est aujourd'hui en cours d'assemblage dans une structure commune avec DORIS, instrument AO fourni par le CNES. Les travaux sur l'ensemble MWR/DORIS devraient se terminer à la fin de l'année.

La fabrication, l'assemblage et les essais des autres modèles de vol d'instruments sont bien avancés. La livraison des dernières unités électroniques des modèles de vol devrait être terminée pour la mi-septembre.

Pour ce qui est de l'antenne ASAR, les chaînes de fabrication des modules d'émission et de réception (TRM) sont désormais pleinement opérationnelles. Le processus d'accord et d'essai du module, opération assez difficile et qui prend du temps, a également été optimisé pour permettre la fabrication industrielle. Plus de 400 TRM auront été fabriqués d'ici la fin du projet.

Secteur sol d'Envisat-1

Les travaux de développement du secteur



des opérations en vol (FOS) et du système de gestion des données de charge utile (PDS) progressent de façon satisfaisante. Le premier exemplaire du logiciel de pilotage a été livré et est intégré à l'ESOC à Darmstadt (D) ; les premiers essais de compatibilité FOS-PPF au niveau des télécommandes et des télémesures sont prévus pour le début de l'automne.

Les travaux d'intégration du PDS se poursuivent. La chaîne qui va de l'enregistrement des données du satellite jusqu'au traitement des images de l'ASAR a déjà été intégrée avec succès et a produit ses premières images SAR générées par le reconditionnement des données du mode imageur SAR de l'AMI fournies par le satellite ERS.

Avec les récentes livraisons de la documentation sur l'algorithme pour le niveau 2 de MIPAS et pour Sciamachy, en provenance des laboratoires de soutien spécialisé (ESL), tous les travaux de développement du processeur des instruments à faible débit de données sont en cours d'exécution dans le cadre du consortium industriel PDS.

Pour ce qui est des activités des Centres de traitement et d'archivage (PAC), le PAC français (F-PAC) reste le seul qui a lancé officiellement ses travaux de développement. Les descriptifs de travaux des autres PAC font l'objet d'itérations.

The Envisat MERIS engineering model

Modèle technologique de MERIS pour Envisat

Météosat

Le satellite du Programme Météosat de transition (MTP) a été lancé par une Ariane 44 LP de Kourou le 2 septembre à 19h21 (heure locale). Désormais dénommé Météosat-7, le satellite devrait arriver à son poste géostationnaire à 10° de longitude ouest le 11 septembre.

La campagne de lancement avait commencé le 3 juillet et la seule activité non nominale qui a dû être entreprise pendant cette période a été le nouvel étalonnage des capteurs solaires à fentes utilisés pour la mesure de l'orientation. Pour ce lancement, Météosat partageait la SPELDA avec, au-dessus de lui, le satellite Hotbird-3.

A ce jour, le lancement et l'exploitation du satellite se sont déroulés de façon nominale, sans aucune anomalie.

La recette en orbite du satellite est du ressort d'Eumetsat et devrait être achevée d'ici la fin octobre ; au-delà de cette date, Météosat-7 rejoindra Météosat-5 et Météosat-6 et, ensemble, ils fourniront régulièrement des cartes météorologiques de l'Europe. Ces trois satellites ont été approvisionnés dans le cadre de contrats d'approvisionnement de véhicules spatiaux de l'ESA.

As regards the ASAR antenna, the manufacturing lines for the Transmit and Receive Modules (TRMs) are now fully operational. The module tuning and testing process, which is a rather challenging and time-consuming task, has also been optimised to allow for industrial series production. By the end of the project, more than 400 TRMs will have been produced.

Envisat-1 ground segment

The Flight Operation Segment (FOS) and Payload Data Segment (PDS) developments are progressing according to plan. A first delivery of the flight-control software is under integration at ESOC in Darmstadt (D), and the first FOS-PPF compatibility tests for telecommanding and telemetry are planned for early fall.

The PDS integration effort continues. The data chain from satellite data recording up to ASAR image processing has already been successfully integrated, producing its first SAR images generated by reconditioning AMI SAR Imaging Mode data provided by the ERS satellite.

With the recent deliveries of the algorithm documentation for MIPAS Level 2 and Sciamachy from Expert Support Laboratories (ESLs), all low-bit-rate instrument processor developments are now in process within the PDS industrial consortium.

With respect to Processing and Archiving Centre (PAC) activities, the French PAC (F-PAC) development is still the only one formally kicked-off. Iterations on the statement of work are in progress with the other PACs.

Meteosat

The Meteosat Transition Programme (MTP) spacecraft was successfully launched by an Ariane 44 LP vehicle from Kourou in French Guiana at 19.21 local time on 2 September. Now known as Meteosat-7, the satellite is expected to arrive at its prescribed geostationary longitude of 10° W on 11 September.

The Meteosat Second Generation primary structure, photographed at Contraves (CH)

Structure primaire de Météosat de deuxième génération, chez Contraves (CH)

The launch campaign was started on 3 July and the only non-nominal activity needed during this period was the successful re-calibration of the Sun-slit sensors used for attitude measurement. For the launch, the satellite, being part of a combined payload, was mounted inside the SPELDA. The other spacecraft being launched at the same time, Hotbird-3, was carried in the upper position.

Both the launch and the operation of the spacecraft to date have been nominal, with no anomalies detected.

The spacecraft commissioning, being performed by Eumetsat, is due to be completed by the end of October, after which Meteosat-7 will join Meteosat-5 and Meteosat-6 in providing the regular weather pictures over Europe. All of these spacecraft have been provided under ESA spacecraft-supply contracts.

the SEVIRI (Scanning Enhanced Visible and Infrared Imager) scanning assembly is still in progress and the SEVIRI scheduling remains on a critical path.

The satellite primary structure for the structural and thermal model has been delivered to the prime contractor Aerospatiale in Cannes (F), where the various subsystems and equipment items will be integrated during the rest of the year.

The development of the MSG-1 spacecraft and the procurement of MSG-2 and -3 are on schedule, with engineering and thermal/mechanical-model production in progress at equipment and subsystem level. The launch of MSG-1 remains on schedule for October 2000, with MSG-2 to be launched in 2002 and MSG-3 to go into storage in 2003.

METOP

By early September, the METOP main development phase was still not fully subscribed. A subscription from the

Meteosat Second Generation

The Preliminary Design Review (PDR) for



Météosat de deuxième génération

La revue de conception préliminaire (PDR) du dispositif de balayage de l'imageur visible et infrarouge amélioré non dégyré (SEVIRI) suit son cours et le calendrier de réalisation de l'instrument reste sur le chemin critique.

La structure primaire du modèle structurel et thermique du satellite a été livrée à Aérospatiale (maître d'oeuvre), à Cannes (F) où les divers sous-systèmes et équipements seront intégrés d'ici la fin de l'année.

Les travaux de développement du satellite MSG-1 et l'approvisionnement des satellites MSG-2 et MSG-3 avancent conformément au calendrier. La production du modèle d'identification et des modèles thermique et mécanique suit son cours au niveau des équipements et sous-systèmes. Le lancement de MSG-1 reste prévu pour octobre 2000, celui de MSG-2 pour 2002 et l'entreposage de MSG-3 se fera en 2003.

METOP

Début septembre, la phase de développement de METOP n'était toujours pas souscrite dans son intégralité. La souscription du Royaume-Uni est imminente mais celles de la Belgique, de l'Espagne et de la France sont toujours en suspens. Pour ce qui est de la France, la réussite du vol Ariane V502 et une évaluation de toutes les conséquences de l'échec V501 sont des conditions préalables à sa participation. Jusqu'à ce que ces souscriptions soient confirmées, le programme reste au point mort.

L'offre industrielle pour la phase C/D a été reçue et est en cours d'évaluation par une équipe mixte ESA/EUMETSAT.

ERS

La prolongation des activités opérationnelles d'ERS (phase E1) a commencé en mai 1997 et se poursuivra jusqu'à la fin 1999. Les souscriptions ont atteint le niveau de 88,79% pour 1997 et 72,08% pour 1998, dans l'attente de la

décision du Royaume-Uni. La Belgique n'a toujours pas souscrit à cette phase.

Le satellite ERS-2 a continué à fournir des données de grande qualité. De petites modifications apportées au logiciel de bord de la charge utile ont permis d'améliorer la disponibilité déjà très bonne des données scientifiques.

Après la défaillance du gyroscope n° 2 en février, l'enquête basée sur l'analyse des données combinée à des simulations au sol a permis de mettre en oeuvre des solutions opérationnelles afin de limiter les conséquences des défaillances ultérieures et de fournir des informations pour les projets futurs. Une liaison a été établie vers ERS-1 et ERS-2 qui est destinée à renforcer les fonctions de surveillance et de récupération du véhicule spatial en cas d'anomalie touchant la commande d'orientation. La surveillance des gyroscopes montre que leur fonctionnement est actuellement stable et que le pointage du satellite est conforme aux spécifications.

ERS-1 sert actuellement de secours à ERS-2 et les vérifications régulières montrent que son niveau de fonctionnement reste bon.

Une campagne d'interférométrie SAR utilisant ERS-1 et ERS-2 qui devrait démarrer le 21 septembre pour un cycle de 35 jours doit compléter la couverture de la Terre en données interférométriques au fur et à mesure que de nouvelles stations sol deviennent opérationnelles.

Station spatiale internationale (ISS)

Élément orbital Columbus (COF)

Toutes les revues préliminaires de conception (PDR) de niveau inférieur ont eu lieu et les préparatifs de la PDR du COF au niveau système, qui devrait démarrer à la mi-octobre, sont bien avancés. Après les PDR au niveau équipements et sous-systèmes, le concept d'ensemble a été affiné et certaines modifications conceptuelles ont été apportées. La revue critique de conception (CDR) des équipements électriques de soutien sol est terminée et le matériel devrait être livré en septembre 1998.

La maquette grandeur nature a été utilisée pour évaluer la configuration générale, l'implantation du câblage et des canalisations, la disposition et l'accessibilité des boîtiers. La première campagne d'essais en micro gravité, pendant laquelle la maquette a été placée dans un caisson d'apesanteur, est également terminée. Les astronautes de l'ESA et de la NASA ont participé à cette campagne et à des simulations des travaux de maintenance en orbite. L'étude visant à établir le meilleur rapport coût/efficacité pour une plate-forme d'observation extérieure a été menée à bien et une proposition sera soumise au Conseil directeur des Programmes spatiaux habités (PB-MS) en septembre.

En ce qui concerne le consortium industriel, presque tous les contrats relatifs aux équipements et aux sous-systèmes sont maintenant signés. L'équipement vidéo est désormais confié à l'industrie européenne : des sociétés italiennes et allemandes prennent en charge cet élément essentiel du projet.

À la suite des importants travaux menés sur la séquence d'assemblage depuis la réunion de mai de la Commission de Contrôle de la Station spatiale (SSCB), la date de lancement du COF devrait être fixée à octobre 2002; l'objectif de l'ESA, qui souhaite un lancement du COF avant fin 2002, serait ainsi respecté.

Le Conseil de l'ESA ayant approuvé sous réserve, en juin, l'Accord de compensation du lancement du COF, l'Agence et la NASA ont continué à rechercher des solutions mutuellement acceptables à la question des droits de propriété intellectuelle. Pour ce qui est de l'arrangement ESA/ASI relatif aux éléments de jonction 2 et 3 (qui dépend du succès des négociations sur l'Accord de compensation du lancement du COF), les demandes de prix en vue de l'approvisionnement des composants européens des éléments de jonction 2 et 3 ont été préparées. Elles devraient être diffusées en septembre, l'objectif étant d'obtenir la participation à part entière des sous-traitants avant la fin de l'année. Les activités relatives aux demandes de prix adressées aux fournisseurs américains pour les composants de l'élément 3 ont démarré et l'on étudie la possibilité d'opter pour des fournisseurs européens dans certains cas.

United Kingdom is imminent, but those of Belgium, Spain and France are still lacking. In France's case, the successful flight of Ariane V502 and an evaluation of the full impact of the V501 failure are pre-requisites for their participation. Until these subscriptions materialise, the Programme remains in limbo.

The industrial offer for Phase-C/D has been received and is under evaluation by a joint team from ESA and Eumetsat.

ERS

The ERS operations extension (Phase-E1) that will last until the end of 1999 started in May this year. Subscriptions have reached levels of 88.79% for 1997 and 72.08% for 1998, pending the United Kingdom's decision. The subscription from Belgium is still outstanding.

The ERS-2 satellite has continued to provide high-quality data. Some small changes to the payload's onboard software have permitted the already very good availability of scientific data to be further increased.

After the gyro-2 failure in February, the investigations based on analysis of the data combined with on-ground simulations have permitted the implementation of operational solutions to limit the impact of subsequent failures and the provision of information for future projects. A path to reinforce the surveillance and recovery of the spacecraft in the event of any attitude-control anomalies has been uplinked to both ERS-1 and ERS-2. Close monitoring of the gyros shows that their performances are currently stable and that satellite pointing is within specification.

ERS-1 is presently serving as a back-up for ERS-2 and the periodic checkouts show that its high performance levels are being maintained.

A SAR interferometry campaign using both ERS-1 and ERS-2 is planned to start on 21 September for one 35-day cycle in order to complete the Earth interferometric data coverage when new ground stations become operational.

International Space Station Programme (ISS)

Columbus Orbital Facility (COF)

All lower-level Preliminary Design Reviews (PDRs) have been completed and preparations for the COF System PDR, due to start mid-October, are well advanced. The equipment-level and subsystem PDRs have led to consolidation of the overall design, with the introduction of a number of design changes. The Electrical Ground-Support Equipment CDR has been completed and hardware delivery is planned for September 1998.

The full-scale mock-up has been used to evaluate the overall configuration layout, harness and plumbing routings, box accommodation and accessibility. The first campaign of zero-g tests, for which the mock-up was placed in a neutral-buoyancy facility, has also been completed. ESA and NASA astronauts participated in the campaign and performed in-orbit-maintenance simulations. The study to determine the most cost-effective means of providing an external viewing capability has been successfully concluded and a proposal will be presented to the Programme Board (PB-MS) at its September meeting.

Within the industrial consortium, almost all sub- and equipment-level contracts have now been signed. Europeanisation of the video equipment has been achieved, with Italian and German companies now undertaking this important work for the

project.

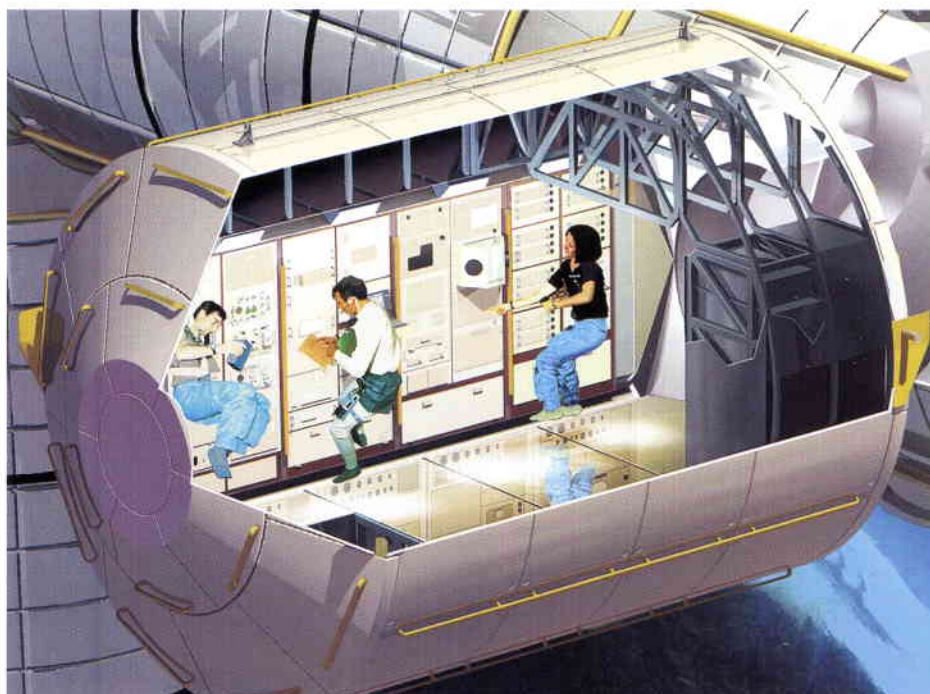
The results of the intensive activities relating to the Space Station Assembly Sequence undertaken since the last Space Station Control Board (SSCB) meeting in May are expected to lead to a COF launch date of October 2002, which would meet ESA's objective of achieving a COF launch before the end of 2002.

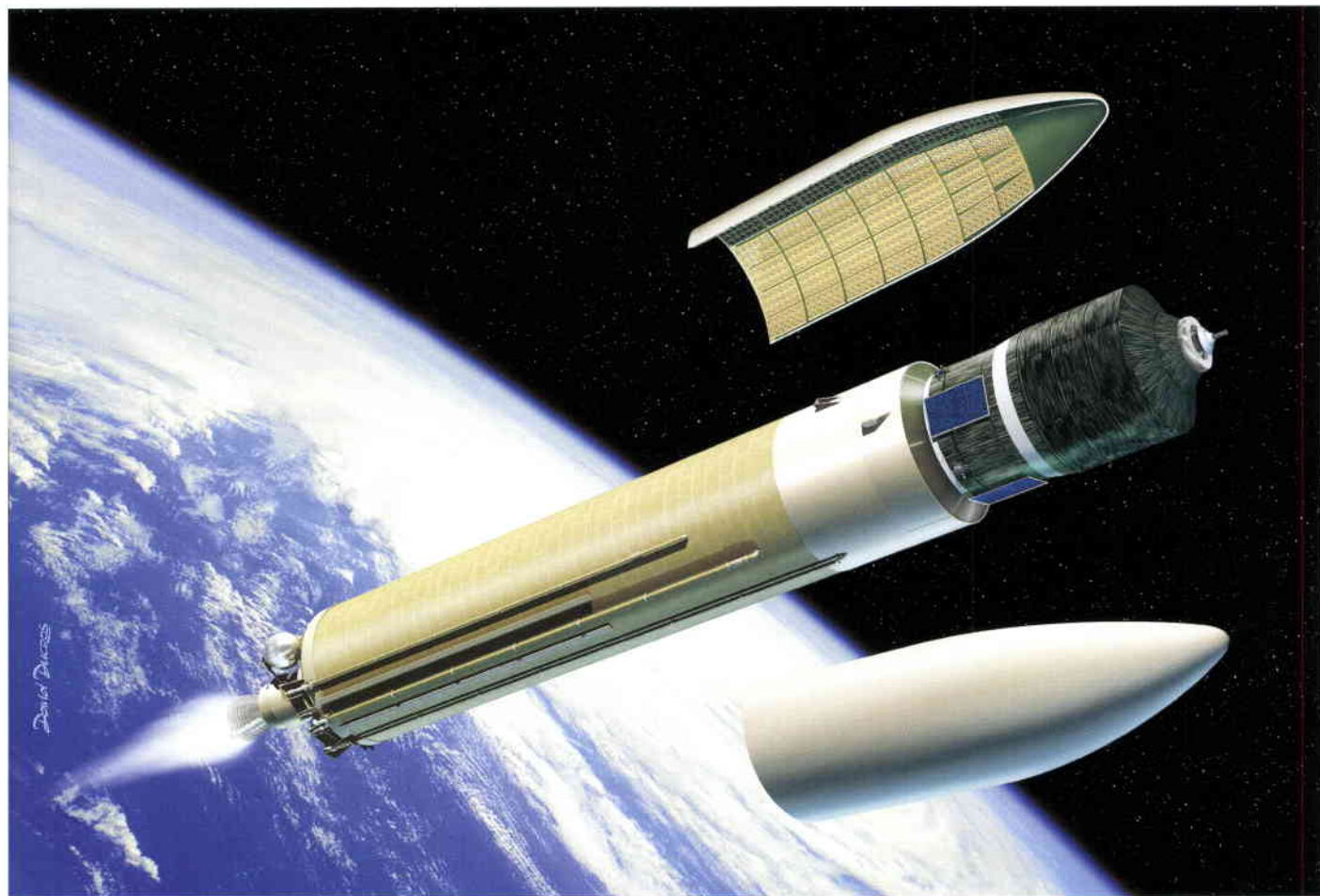
Subsequent to the conditional approval of the COF Launch Barter Agreement by the ESA Council in June, ESA and NASA have pursued their efforts to identify mutually acceptable solutions on the intellectual property rights issue. In the frame of the ESA/ASI Node-2/Node-3 Arrangement (which depends on the successful conclusion of the COF Launch Barter Agreement), the Requests for Quotation (RFQs) for the procurement of the European items for Nodes 2 and 3 have been prepared. They are due for release in September, the goal being to have subcontractors fully involved before the end of the year. Activities related to RFQs to US suppliers for Node 3 items, as well as the possibility of obtaining alternative European suppliers for some items, have begun.

The acceptance and transfer of ownership process concerning the MPLM ECLSS

The Columbus Orbital Facility (COF)

L'élément orbital Columbus (COF)





La procédure de recette et de transfert de propriété de l'ECLSS (sous-système de régulation d'ambiance et de soutien vie) du MPLM entre l'ESA et l'ASI suit maintenant son cours. La livraison des équipements de soutien sol et de tous les équipements du modèle d'identification a été officialisée.

Tous les essais de qualification au niveau sous-systèmes sont terminés. Toutefois, les essais de qualification au niveau équipements s'étant achevés tardivement aux Etats-Unis et en Europe, la revue de qualification au niveau sous-systèmes de l'ECLSS dans son ensemble devrait être reportée à fin novembre. Les retards de la qualification se répercutent sur la livraison des modèles de vol au maître d'oeuvre du MPLM, maintenant fixée à décembre.

Véhicule de transfert automatique (ATV)

Une extension du contrat de phase B2 a été approuvée, ce qui permet de maintenir l'équipe industrielle et de démarrer les activités anticipées de phase C/D, de façon à respecter le calendrier. L'industrie met la dernière main à sa proposition de phase C/D en vue de la soumettre à l'ESA le 29 septembre. Comme l'ont demandé

les délégations, des observateurs de l'ESA ont participé à l'évaluation de plusieurs propositions concurrentes au niveau équipement.

La définition des interfaces Ariane-5/ATV se poursuit comme prévu, l'objectif étant de réaliser le vol de démonstration de l'ATV sur la version nominale d'Ariane-5. Les discussions se poursuivent entre l'ESA et le CNES sur le descriptif des travaux d'adaptation d'Ariane-5. Les appels d'offres devraient être envoyés à l'industrie en septembre.

En ce qui concerne le programme ARP, la préparation du troisième vol de démonstration (sur le vol STS-86 de la Navette, prévu le 25 septembre) se poursuit conformément au calendrier. Il faudra prendre en compte, pour établir les trajectoires définitives d'approche et de séparation Navette/Mir, les besoins identifiés lors de l'enquête sur les dommages provoqués par la collision entre Progress et Mir.

Véhicule de transport d'équipages (CTV)

Le PB-MS ayant donné son approbation en mai, le contrat d'étude de phase B a

The ATV on Ariane-5 at fairing jettison

L'ATV sur Ariane-5 après largage de la coiffe

été réorienté de façon à mettre l'accent sur les activités relatives aux corps portants. Pour ce qui est de la coopération entre le X-38 de la NASA et le CTV/CRV (véhicule de sauvetage de l'équipage), un protocole a été signé avec le Bureau du Programme de Station spatiale visant deux 'accords de principe', l'un sur les modalités de cette coopération, l'autre avec le projet X-38 sur le contenu spécifique de cette coopération.

Activités opérationnelles et secteur sol

L'étude de définition des installations et fonctions de contrôle des opérations du COF/ATV (commencée en avril) a passé avec succès l'étape de la revue d'évaluation en juin. La définition préliminaire de l'architecture a ensuite été examinée début août et la revue du plan de mise en oeuvre est prévue fin septembre.

(Environmental Control and Life Support Subsystem) between ESA and ASI is now working well, and delivery has been formalised for the Ground-Support Equipment items and all delivered engineering-model equipment.

Subsystem-level qualification tests have all been completed. However, due to the late close-out of equipment-level qualification testing both in the USA and in Europe, the overall ECLS Subsystem Qualification Review is now expected to be delayed until the end of November. The qualification delays are cascading into the flight-unit deliveries, units of which are now scheduled to be delivered to the MPLM Prime Contractor in December.

Automated Transfer Vehicle (ATV)

An extension of the Phase-B2 contract has been approved, ensuring industrial-team continuity and the start-up of advanced Phase-C/D activities to secure the Phase-C/D schedule. Industry is finalising its Phase-C/D proposal for submission to ESA on 29 September. As requested by Delegations, ESA observers have participated in the evaluation of several competitive proposals at equipment level.

Ariane-5/ATV interface definition is progressing as planned, with the objective of securing the ATV demonstration flight on the nominal Ariane-5 version. Discussions between ESA and CNES on the Statement of Work for the Ariane-5 adaptation are still in progress. It is planned to issue Invitations to Tender (ITTs) to industry in September.

Within the ARP programme, the preparation of demonstration flight no. 3 (on Shuttle flight STS-86, planned for 25 September) is on schedule. For the finalisation of the Shuttle-Mir approach and departure trajectories, requirements resulting from the investigation of the Progress-Mir collision damage have to be taken into account.

Crew Transfer Vehicle (CTV)

Following the approval by the Manned Space Programme Board (PB-MS) in May, the Phase-B study contract has been further reoriented with the emphasis on lifting-body activities. In the context of the X38 - CRV/CTV cooperation activity with NASA, a Protocol with the Space Station Programme Office aiming at an 'Agreement in Principle' on the

cooperation scheme and another with the NASA X-38 project on the specific content of the X-38 cooperation have been signed.

Operations and ground segment

The definition study of the COF/ATV Operations Control Functions and Facilities (started in April) successfully passed its Assessment Review milestone in June. The preliminary architecture definition was subsequently reviewed in early August, and the Implementation Review is scheduled for the end of September.

The definition study of the COF/ATV Operations Support Functions and Facilities, initiated at the end of May, successfully passed its Assessment Review in early August. The Implementation Review is scheduled for the beginning of October.

The Implementation Baseline Review of the definition study on the Ground Communications Infrastructure was performed in early August. The Final Review is scheduled for end-October.

Utilisation

In the context of the Early Opportunities activities, the selection of external payloads is in process. The initial ten groupings based on the results of the peer evaluation have been reduced to seven, which were approved in July by the European Utilisation Board (EUB) for further technical analysis. The results will be presented to the EUB in mid-September. Besides technical constraints, the availability of funds for the recommended experiments will be the next primary selection filter.

First accommodation studies for External Payloads on the ISS Express Pallets have led to a number of groupings suitable for the three ESA-reserved Adapters. Key technical characteristics inherent in the European Express Pallet payload groupings have been presented to NASA for assessment (re impact on instruments located on neighbouring Pallet Adapters, impact on ISS operations, impact on overall power and communications resources, etc.). In parallel, the programmatic and schedule aspects of the ESA-delivered integrated Express Pallet Adapters are under discussion with NASA.

Astronaut activities

On 24 July, ESA astronaut Thomas Reiter was awarded the Russian 'Soyuz Return

Commander' certificate at the Yuri Gagarin Cosmonaut Centre. He is the first non-Russian astronaut to be awarded this certificate, which qualifies him to be the Commander of a three-person Soyuz capsule during its return from space.

With Thomas Reiter's new certification, ESA has its first astronaut qualified to return a capsule rescue vehicle from the International Space Station. The knowledge acquired by Reiter during the training programme also provides ESA with valuable input for its European Crew Transport/Crew Rescue Vehicle (CTV/CRV) activities.

Early Deliveries

Data Management System for the Russian Service Module (DMS-R)

Additional software changes requested by RSC-Energia have been settled contractually and implemented into the DMS-R design.

During July and August, all DMS-R engineering-model hardware, software and associated ground-support equipment was shipped to Russia and installed at RSC-Energia. The DMS-R qualification test programme has been completed. The Qualification Review started in August, with the final board session scheduled for the end of September. Manufacture of the first set of flight units was completed by end-July and acceptance testing is currently in progress. The first flight-unit delivery is planned for mid-October.

The scope of the engineering support to Russia through August 1999 (until three months after US Lab launch) and the subsequent long-term support during the operational phase has been defined. As far as long-term support is concerned, the concept of a barter arrangement providing European DMS-R support in return for Russian ATV integration work on the Russian Segment is currently under review.

European Robotic Arm (ERA)

Manufacture and testing of the ERA engineering qualification models is underway for most subsystems. These models are used for thermal and structural qualification testing and for functional development. The schedule is under final revision/consolidation to reflect the new flight-hardware delivery dates which are under discussion with the Russian Space Agency following the delay in the ERA's

L'étude de définition des installations et fonctions de soutien des opérations du COF/ATV, commencée fin mai, a passé avec succès la revue d'évaluation début août. La revue du plan de mise en oeuvre est prévue début octobre.

En ce qui concerne l'étude de définition de l'infrastructure de communication au sol, la revue du plan de mise en oeuvre a eu lieu début août. La revue finale est prévue fin octobre.

Utilisation

Le choix des charges utiles externes qui seront embarquées dans le cadre des occasions de vol initiales est en cours. Les dix lots retenus dans un premier temps à la suite de l'évaluation des experts ont été ramenés à sept; la Commission européenne de l'utilisation (EUB) a approuvé en juillet la poursuite de l'analyse technique. Les résultats lui seront présentés à la mi-septembre. Outre les contraintes techniques, le choix dépendra ensuite essentiellement de la disponibilité des crédits nécessaires pour mener les expériences recommandées.

Les premières études relatives à l'installation des charges utiles externes sur les palettes express de l'ISS ont conduit à la constitution d'un certain nombre de lots pour les trois adaptateurs attribués à l'ESA. Les principales caractéristiques techniques des lots de charges utiles destinés aux palettes express européennes ont été présentées pour évaluation à la NASA (incidences sur les instruments des adaptateurs de palettes situés à proximité, sur les opérations de l'ISS, sur l'ensemble des ressources au niveau énergie et communications, etc). Parallèlement, les questions programmatiques et le calendrier des adaptateurs intégrés de palette express livrés par l'ESA sont examinés avec la NASA.

Activités des astronautes

Le 24 juillet, l'astronaute de l'ESA Thomas Reiter a reçu le brevet de 'Commandant pour le retour de Soyouz' au Centre de formation des cosmonautes Youri Gagarine. Il est le premier astronaute non russe à obtenir ce brevet, qui le qualifie pour piloter une capsule Soyouz lors de son retour à Terre avec ses trois passagers.

Thomas Reiter devient ainsi le premier astronaute de l'ESA qualifié pour ramener

à Terre un véhicule de sauvetage en provenance de la Station spatiale internationale. Les connaissances acquises par Thomas Reiter pendant sa formation seront également mises à profit par l'ESA dans ses activités relatives au CTV/CRV.

Livraisons à court terme

Système de gestion des données pour le module de service russe (DMS-R)

Les modifications supplémentaires du logiciel demandées par RKK Energia ont été convenues sur le plan contractuel et leur introduction dans le concept du DMS-R est en cours.

En juillet et août, tous les matériels et logiciels du modèle d'identification du DMS-R et les équipements de soutien sol associés ont été envoyés en Russie et installés chez RKK Energia. Le programme d'essais de qualification du DMS-R est terminé. La revue de qualification a démarré en août et la dernière session de la commission est prévue fin septembre. La fabrication de la première unité de vol s'est achevée fin juillet et les essais de recette sont en cours ; la livraison est prévue mi-octobre.

La nature du soutien technique qui sera apporté à la Russie jusqu'à août 1999 (trois mois après le lancement du laboratoire américain) et du soutien à long terme qui sera ensuite nécessaire pendant la phase d'exploitation a été définie. Pour ce qui est du soutien à long terme, on étudie actuellement l'idée d'un accord de compensation prévoyant le soutien de l'Europe pour le DMS-R en échange de travaux d'intégration de l'ATV par la Russie sur la composante russe.

Bras télémanipulateur européen (ERA)

La fabrication et les essais des modèles de qualification technique de l'ERA sont en cours pour la plupart des sous-systèmes. Ces modèles sont utilisés pour les essais de qualification thermique et structurelle et pour la mise au point du fonctionnement de l'ERA. Une dernière révision/harmonisation du calendrier est en cours afin de prendre en compte les nouvelles dates de livraison du matériel de vol, qui sont examinées avec l'Agence spatiale russe à la suite du report du lancement de l'ERA sur la plate-forme russe 'science et énergie'.

Equipements de soutien de laboratoire (LSE)

La PDR du MELFI (congélateur de

laboratoire à -80° C), qui a démarré en avril avec la participation de la NASA et de la NASDA, se poursuit de façon satisfaisante. La documentation est en cours d'actualisation. La dernière réunion de la commission est prévue début octobre, de même que celle de la commission chargée de la MSG (boîte à gants de recherche en micro gravité). L'industrie a soumis fin juillet sa proposition de phase C/D pour Hexapod.

Microgravité

EMIR-1

Un symposium faisant suite à la mission Biorack menée à bien lors du vol STS-84 de la Navette se tiendra en avril/mai 1998 à Bruxelles afin d'examiner les résultats des trois derniers vols du Biorack, en liaison avec un atelier qui doit être organisé par le groupe de travail international sur les sciences de la vie (ILSWG).

Les préparatifs de la mission Photon-11 ont repris après une longue interruption. La charge utile de l'ESA se compose du Biobox 3 et du Biopan 2. En, juillet, le matériel de vol a été testé avec le satellite dans l'usine de fabrication des Progress. Les unités de vol du Biobox et du Biopan ont été réexpédiés à l'ESTEC en août en vue de l'étalonnage du Biobox, de l'installation de détecteurs et de l'application d'une peinture blanche spéciale sur le Biopan, du parachèvement du logiciel de contrôle avec les paramètres de mission, de l'installation de nouvelles batteries et de la vérification des conteneurs de transport à régulation thermique. Les autorités russes ont fixé le lancement de Photon-11 au 8 octobre.

Il a été confirmé fin juin que le FluidPac ferait partie de la charge utile ESA qui serait embarquée sur Photon-12. Le modèle de qualification est maintenant presque entièrement assemblé. Tous les sous-systèmes ont été soumis aux essais d'ambiance et sont qualifiés. Les essais de qualification au niveau système doivent s'achever fin septembre. Il est maintenant admis que la mission Photon-12 aura lieu au printemps 1999.

La préparation de la mission mini-Texus 5 se déroule conformément au calendrier. Le lancement est prévu début décembre. Celui des missions Mini-Texus 6 (expérience de combustion) et 7

launch on the Science and Power Platform of the Russian Segment.

Laboratory Support Equipment (LSE)

The Preliminary Design Review (PDR) — started in April with NASA and NASDA participation — for the MELFI (Minus Eighty Degree Laboratory Freezer) has progressed successfully. The documentation is being updated accordingly. The PDR Final Board meeting is scheduled for early October, as is that for the MSG (Microgravity Science Glovebox). Industry submitted its Hexapod Phase-C/D proposal at the end of July.

Microgravity

EMIR-1

Following the successful Biorack mission in May on Shuttle flight STS-84, a Symposium is planned in April/May 1998 in Brussels to review the results of the last three Biorack flights, in combination with a Workshop to be organised by the International Life-Science Working Group (ILSWG).

After a long delay, preparations for the Foton-11 mission have been restarted. The ESA payload for this mission consists of Biobox-3 and Biopan-2. The flight hardware was successfully tested with the satellite in July at the Progress factory. The Biobox and the Biopan flight units were subsequently shipped back to ESTEC in August for calibration of the Biobox, the installation of sensors and the application of a special white paint to Biopan, the completion of the control software with the mission parameters, the installation of new batteries, and checkout of the thermally controlled transport containers. The Foton-11 launch date has been set by the Russian authorities for 8 October.

At the end of June, the FluidPac was confirmed as part of ESA's payload on Foton-12. The qualification model is now almost fully assembled. All subsystems have been environmentally tested and qualified. The qualification test at system level is scheduled for completion at the end of September. Spring 1999 is now the assumed Foton-12 mission date.

The preparation of the Mini-Texus 5 mission is proceeding on schedule, with the launch planned for early December. The Mini-Texus 6 (combustion experiment)

and 7 (droplet-evaporation experiment) missions are both scheduled for launch in November 1998, after the Maxus-3 mission with five experiment modules.

EMIR-2

The upgrading of the two flight units of the Advanced Protein Crystallisation Facility (APCF) is progressing well. The functional performance and acceptance testing of the refurbished hardware will be carried out in October, and thereafter the facility will be ready for its next mission on Spacehab in October 1998 (on Shuttle flight STS-95).

Further to the inspection of and the definition of the necessary refurbishment for the Advanced Gradient Heating Facility (AGHF), preparation of the AGHF for re-flight on Spacehab in 1998 is in full swing.

Post-flight evaluation of the MOMO (Morphological Transition and Model Substances) experiment data is progressing with the evaluation of the data returned. First results indicate only partial experiment success, due to the thermal anomalies that occurred during the STS-84 mission in May. Current plans call for a re-flight on STS-95 in October 1998, assuming that the earlier failure(s) can be clearly identified and eliminated and that the necessary funding can be obtained.

As part of a broader human physiological research package, and in collaboration with CNES, the Advanced Respiratory Monitoring System (ARMS) is a candidate for their planned 120-day Mir-99 mission. In view of the uncertainties associated with Mir's future, an alternative flight opportunity on one of the new Spacehab missions is also being considered.

Microgravity Facilities for Columbus (MFC)

The MFC Programme, formally initiated on 1 January this year, includes several multi-user facilities: the Biolab, the Fluid-Science Laboratory (FSL), the Material-Science Laboratory (MSL) and the European Physiology Modules (EPM). New elements have also been added to the Programme, such as the Bioglovebox and the Experiment Processing Unit (EPU) for Biolab. The Bioglovebox was originally planned to be part of EMIR-2, whilst the EPU became necessary because the majority of the biological experiments have to be prepared in-orbit prior to their processing in Biolab.

The Biolab Phase-C/D Request for Quotation (RFQ) was released in mid-July and submission of the industrial consortium's proposal is due by the end of September. The Phase-C/D itself is planned to start during the last quarter of this year.

The FSL Phase-B Mid-Term Design Review was successfully completed in July. The Phase-B final presentation will take place in early November, and the RFQ for Phase-C/D will be issued shortly thereafter. The FSL Phase-C/D will be initiated in March 1998.

NASA is scheduled to provide preliminary rack-interface definition data for the MSL's accommodation inside the US Lab, by the end of September. These data will form the basis for study of the MSL's accommodation in the US module, for the completion of Phase-B which is planned for early 1998.

The Invitation to Tender (ITT) for the EPM was released in June, incorporating the input from the dedicated Science Team. The Phase-A contract is to be initiated in October.

EUROMIR-E

At the end of June, Mir Crew No. 24 — consisting of Alexander Solovyev and Pavel Vinogradov — completed their experiment training in preparation for the EUROMIR-E mission. The main set of resupply hardware for the mission was delivered to Mir by an unmanned Progress vehicle on 7 July.

Following the 25 June collision at Mir and the subsequent loss of approximately 35% of the station's power, the scientific activities onboard came to a halt. The subsequent investigations by the crew have revealed that the majority of the EUROMIR-E experiment hardware is located in the damaged Spektr module and cannot currently be reached. In the meantime, Mir Crew No. 24 was launched on 5 August and docked successfully with the station on 7 August.

On 22 August, A. Solovyev and P. Vinogradov donned their EVA suits and entered the depressurised Spektr module, where they reconnected Spektr's solar-power generators to the main part of the Mir station, thereby restoring its power-generation capability. However, no ESA scientific equipment could be recovered

(expérience d'évaporation de gouttelettes) est fixé à novembre 1998, au-delà de la mission Maxus-3 qui emportera cinq modules d'expériences.

EMIR-2

La mise à hauteur des deux unités de vol de l'installation de cristallisation des protéines de pointe (APCF) progresse de façon satisfaisante. Les essais de fonctionnement et de recette du matériel remis en état seront conduits en octobre à la suite de quoi l'installation sera prête pour sa prochaine mission qui se déroulera à bord du Spacehab en octobre 1998 (vol Navette STS-95).

Le four à gradient de haute technologie (AGHF) ayant été inspecté et les travaux de remise en état nécessaires définis, les préparatifs de réemport de ce four en 1998, à bord du Spacehab, battent leur plein.

L'analyse après vol des données de l'expérience MOMO (études de transition morphologique sur des substances modèles) est en cours. Il ressort des premiers résultats que l'expérience n'a que partiellement réussi en raison des anomalies thermiques survenues pendant la mission STS-84 qui a eu lieu en mai. On prévoit actuellement le réemport de l'expérience en octobre 1998 lors de la mission STS-95, à supposer que la ou les défaillances antérieures puissent être clairement cernées, leur récurrence évitée et les crédits nécessaires obtenus.

Dans le cadre d'un programme plus vaste de recherche en physiologie humaine, et en collaboration avec le CNES, le système de surveillance respiratoire de pointe (ARMS) est candidat à l'emport lors de la mission Mir de 120 jours prévue en 1999. Compte tenu des incertitudes qui planent sur l'avenir de Mir, on envisage également une possibilité d'emport lors de l'une des nouvelles missions Spacehab.

Installations de recherche en micro-gravité pour Columbus (MFC)

Le programme MFC, qui a officiellement commencé le 1er janvier dernier comporte plusieurs installations à utilisateurs multiples : le Biolab, le laboratoire de sciences des fluides (FSL), le laboratoire de sciences des matériaux (MSL) et les modules de physiologie européens (EPM). De nouveaux éléments ont été inclus dans le programme tels la boîte à gants biologique et l'unité de préparation

d'expériences (EPU) destinée au Biolab. A l'origine, il était prévu que la boîte à gants biologique fasse partie du programme EMIR-2; quant à l'EPU, elle s'est avérée nécessaire car la majorité des expériences biologiques doivent faire l'objet d'une préparation en orbite avant leur déroulement dans le Biolab.

Le demande de prix (RFQ) portant sur la phase C/D du Biolab a été adressée mi-juillet au consortium industriel qui doit remettre sa proposition fin septembre. La phase C/D elle-même devrait commencer dans le courant du dernier trimestre 1997.

La revue de conception à mi-parcours (Phase B) du FSL été menée à bien en juillet. La présentation de fin de phase B aura lieu début novembre et la RFQ relative à la phase C/D sera publiée peu après. La phase C/D du FSL commencera en mars 1998.

La NASA doit fournir fin septembre des données préliminaires pour la définition de l'interface bâti/MSL en vue de l'installation du MSL à l'intérieur du laboratoire américain. C'est sur ces données que reposera l'étude d'implantation du MSL dans le module américain qui doit permettre de clore la phase B au début de 1998.

L'appel d'offres relatif à l'EPM a été lancé en juin. Il tenait compte des données fournies par l'équipe scientifique spécialisée. Les travaux à réaliser sous couvert du contrat de phase A doivent commencer en octobre.

EUROMIR-E

Fin juin, le 24ème équipage de Mir, composé d'Alexandre Solovyev et de Pavel Vinogradov, a terminé sa formation préparatoire à la réalisation des expériences de la mission EUROMIR-E. La majeure partie du matériel à réapprovisionner pour la mission a été livrée à la station Mir le 7 juillet au moyen d'un cargo Progress automatique.

En raison de la collision qui s'est produite sur Mir le 25 juin, la station est privée d'environ 35% de sa puissance électrique, ce qui a conduit à l'arrêt des expériences scientifiques. Les investigations ultérieures conduites par l'équipage ont fait apparaître que la majeure partie du matériel nécessaire aux expériences d'EUROMIR-E se trouve dans le module Spektr endommagé et n'est pas

accessible pour le moment. Cependant, le 24ème équipage de Mir, parti le 5 août, a pu s'amarrer sans encombre à la station le 7 août.

Le 22 août, A. Solovyev et P. Vinogradov ont revêtu leurs combinaisons spatiales et ont pénétré dans le module Spektr où ils ont réussi à reconnecter les générateurs solaires du module à la partie centrale de la station Mir, rétablissant ainsi sa capacité de production d'énergie. Malheureusement, le matériel scientifique de l'ESA n'a pu être sorti de Spektr et les cosmonautes n'ont pas non plus réussi à localiser la perforation au cours de cette visite ni lors de la sortie extra-véhiculaire effectuée le 6 septembre par A. Solovyev et l'astronaute américain M. Foale.

La question de savoir si le programme d'expériences dont il avait été convenu pour Euromir-E pourra être exécuté par un futur équipage de Mir sera examinée avec les autorités russes une fois que l'état de fonctionnement de la station aura été amélioré.

Programme de démonstration technologique en orbite

DDE (Expérience de détecteur de décharge)

La phase de définition (étude de phase A) s'est achevée en avril. Entre les mois de mai et août, se sont déroulées les activités de consolidation de la conception et de définition des interfaces de la DDE avec le véhicule spatial (NPO PM) et le système de télémesures (Université de Novosibirsk). NSU a terminé l'étude et les essais nécessaires à la définition de l'épaisseur des boîtiers exposés au vide spatial ainsi que le type et la taille des matériaux diélectriques qui seront utilisés pour cette expérience.

Le montage table de l'expérience DDE doit être fabriqué et testé en janvier 1998. La fabrication, l'étalonnage et les essais électriques du modèle de vol de la DDE doivent être terminés en avril 1998 et l'expérience doit être prête à être livrée à NPO PM, pour intégration et essai sur le véhicule spatial ESPRESS-13 pour la fin juillet 1998. Le véhicule spatial doit être lancé en décembre 1998 et restera opérationnel pendant 30 mois (durée de vie minimale escomptée de l'expérience).

from Spektr, nor could the puncture in its hull be located during this visit, nor during the subsequent EVA performed on 6 September by A. Solovyev and US Astronaut M. Foale.

Whether the agreed EUOMIR-E experiment programme can be conducted by a future Mir crew will be negotiated with the Russian authorities once the station has been restored to better operational status.

In-Orbit Technology Demonstration Programme

DDE (Discharge Detector Experiment)

The definition phase (Phase-A study) was completed in April. Between May and August, both the consolidation of the design and the definition of the DDE's interfaces with the spacecraft (NPO PM) and the telemetry system (Novosibirsk State University) have taken place. NSU has completed the study and testing necessary to define the thickness of the space-exposed boxes and the type and size of the dielectric materials that will be used in the experiment.

The DDE experiment (breadboard) is to be manufactured and tested in January 1998. The manufacture, calibration and electrical testing of the DDE flight unit are to be completed in April 1998, and the experiment must be ready for delivery to NPO PM for integration and testing on the ESPRESS-13 spacecraft at the end of July 1998. The spacecraft is scheduled for launch in December 1998 and will be operational for 30 months (minimum expected lifetime of the experiment).

FEED (Field-Emission Electric Propulsion)

The proposal for the development and flight demonstration of the FEED system has been accepted for evaluation. This proposal takes into account both potential commercial (millinewton thrust) and scientific (micronewton thrust) applications of the technology. This propulsion system will be demonstrated using a Get-Away Special (GAS) canister launched on a Space Shuttle in 1999. The work will start in October.

JERICO (Joint European Robotics and Interactive Calibrated Operations)

The second phase of the project, covering system development, integration and operations, is currently on hold. JERICO should have been installed on the Russian Mir space station, to form a unique external payload-servicing facility with the Russian Pelikan robotic system, for which a cooperative agreement between RSC-Energia and ESA/ASI had been negotiated.

Given the current situation on the station, new accommodation studies are in progress. Among other options, the project team is investigating placing the JERICO robotic system on the Russian Service Module of the International Space Station. A final decision about its accommodation can be expected in October, by which time the Russian Space Agency should have decided on how to proceed with the Pelikan robotic system.

ASI's role in JERICO, namely the system development, testing and delivery of the robotic system, is progressing well and is unaffected by the above developments.

PROBA (Project for On Board Autonomy)

One industrial proposal, received in June, was accepted for evaluation. The latter revealed that although the proposal contained a number of positive points, overall it could not be considered sufficiently mature for an immediate programme start. Therefore, in order to avoid excessive delay, it was decided to start a preliminary mission design phase, leading to a fully consolidated set of system specifications. Once these are accepted, the consortium led by Verhaert (B) will resubmit a proposal covering all of the remaining project activities. ESA will then resume the evaluation exercise, which is presently on hold.

The process of selecting suitable payloads for PROBA, which is to be launched into a Sun-synchronous orbit by the end of 1999 or in 2000, has been started.

STOF (Slosh Test Orbital Facility)

This Shuttle Hitchhiker payload is composed of the Sloshsat satellite and the so-called ESAJECT ejection system.

Sloshsat is a small free-flying spacecraft that will be ejected from a Hitchhiker Pallet in the Shuttle's cargo bay, using the ESA-

developed ejection and communication system. It is designed to investigate the forces exerted on a manoeuvring spacecraft by a liquid sloshing in a partially filled onboard tank. Sloshsat will be operated for the duration of the Shuttle flight from a ground station at NASA's Goddard Space Flight Center, using the Shuttle as a communications relay, and will not be retrieved. ESA and NASA have recently signed a Letter of Agreement providing for the free launch of STOF in exchange for experiment resources and the residual ESAJECT flight hardware.

The main contractor for Sloshsat is NLR (NL), and that for ESAJECT is Verhaert (B).

Following a subsystem Critical Design Review (CDR) in January, the Sloshsat satellite CDR took place in May. It showed that additional design work was needed before being able to proceed with manufacturing and verification activities.

The ESAJECT CDR took place in April 1997. Its design was considered mature, but certain design changes requested by NASA during the recent Safety Review have to be accommodated.

TPX II (Two-Phase Flow Experiment II)

The experiment's preparation is proceeding according to plan and ESA expects to deliver TPX II to NASA later this year. Due to a recent change in Shuttle safety requirements, the experiment is currently undergoing a series of additional tests. Launch of TPX II is planned for early 1998.



FEEP (propulsion électrique par émission de champ)

La proposition de développement et de démonstration de vol du système FEEP a été acceptée pour évaluation. Cette proposition tient compte des applications potentielles commerciales (poussée de l'ordre du millinewton) et scientifiques (poussée de l'ordre du micronewton). Ce système fera l'objet d'une démonstration au moyen d'un conteneur GAS (offre spéciale de vol) qui sera embarqué sur une navette spatiale en 1999. Les travaux commenceront en octobre.

JERICO (Projet commun européen d'étalonnage interactif de robotique)

La deuxième phase du projet qui couvre la mise au point, l'intégration et l'exploitation du système est actuellement à l'arrêt. JERICO aurait dû être installé sur la station spatiale russe Mir pour constituer avec le système robotique russe Pelikan une installation unique d'entretien et de dépannage de charges utiles extérieures, pour laquelle un accord de coopération avait été négocié entre RSC-Energia et l'ESA/ASI.

Compte tenu de l'état actuel de la station, on procède actuellement à une nouvelle étude d'implantation. Entre autres possibilités, l'équipe de projet étudie la possibilité de placer le système robotique JERICO sur le module de service russe de la Station spatiale internationale. Une décision définitive sur son implantation devrait être prise en octobre ; d'ici là, l'Agence spatiale russe devrait avoir décidé de la conduite à tenir en ce qui concerne le système robotique Pelikan.

Les travaux incombant à l'ASI dans le cadre du projet JERICO, à savoir la mise au point, l'essai et la livraison du système robotisé, avancent conformément aux prévisions et ne sont pas affectés par les événements ci-dessus.

PROBA (Projet pour l'autonomie de bord)

Une proposition industrielle, reçue en juin, a été acceptée pour évaluation. Il en ressort que si la proposition contient un certain nombre de points positifs, on ne peut pas, de manière générale, la considérer comme suffisamment mûre pour autoriser un démarrage immédiat du programme. Afin de ne pas prendre trop de retard, il a par conséquent été décidé de lancer une phase préliminaire de conception de la mission qui débouchera

sur un ensemble entièrement consolidé de spécifications système. Une fois celles-ci approuvées, le consortium dirigé par Verhaert (B) soumettra une nouvelle proposition couvrant tout le reste du projet. L'ESA reprendra alors son évaluation qui est pour l'instant au point mort.

La procédure de sélection des charges utiles de PROBA a commencé. PROBA doit être lancé sur une orbite héliosynchrone à la fin de 1999 ou en l'an 2000.

STOF (Installation orbitale d'essais de ballottement)

Cette charge utile destinée à la structure porteuse Hitchhiker de la Navette, se compose d'un satellite Sloshsat et du système d'éjection ESAJECT.

Sloshsat est un petit satellite autonome qui sera largué à partir d'une structure porteuse Hitchhiker placée dans la soute de la Navette au moyen du système de télécommunications et d'éjection mis au point par l'ESA. Il est conçu pour étudier les forces qu'exerce lors des manoeuvres du satellite un liquide ballottant dans un réservoir partiellement vide. Sloshsat sera piloté pendant tout le vol de la Navette à partir d'une station sol du Goddard Space Flight Center de la NASA qui utilisera la Navette comme relais de télécommunications. Sloshsat ne sera pas récupéré. L'ESA et la NASA ont récemment signé une lettre d'Accord qui prévoit le lancement gratuit de STOF en échange de ressources d'expériences et du matériel de vol restant d'ESAJECT.

La maîtrise d'oeuvre de Sloshsat a été confiée à NLR (NL) et celle d'ESAJECT à Verhaert (B).

La revue critique de conception (CDR) du satellite Sloshsat s'est déroulée en mai, après la revue critique de conception (CDR) au niveau des sous-systèmes qui s'était tenue en janvier. Elle a montré que des travaux de conception supplémentaires seraient nécessaires avant que l'on puisse passer aux activités de fabrication et de vérification.

La CDR d'ESAJECT s'est tenue en avril 1997. Le concept a été jugé mûr mais il faudra y intégrer certaines modifications demandées par la NASA durant la revue de sécurité qui s'est tenue récemment.

TPX II (Expérience d'écoulement diphasique II)

La préparation de l'expérience progresse conformément aux prévisions et l'ESA compte pouvoir livrer l'expérience TPX II à la NASA d'ici la fin de l'année. La NASA ayant récemment modifié les impératifs de sécurité de la Navette, l'expérience fait actuellement l'objet d'une série d'essais supplémentaires. Son lancement est fixé à début 1998.



SOHO Scientists Discover Massive Jet Streams Inside the Sun

For the last year, the Solar and Heliospheric Observatory (SOHO) spacecraft has been aiming its battery of 12 scientific instruments at the Sun from a position 1.5 million km sunward from the Earth. Scientists using this joint ESA/NASA spacecraft have discovered 'jet streams' or 'rivers' of hot, electrically-charged gas called plasma flowing beneath the surface of the Sun. They have also found features similar to the Earth's tradewinds that transport gas beneath the Sun's fiery surface.

These new findings will help us to understand the famous sunspot cycle and associated increases in solar activity that can affect the Earth with power and communications disruptions. The observations are the latest made by the Solar Oscillations Investigation (SOI) group at Stanford University, CA, and build on the many discoveries made by the SOHO science team over the past year. "We have detected motion similar to the weather patterns in the Earth's atmosphere," said Dr. Jesper Schou of Stanford. "Moreover, in what is a completely new discovery, we have found a jet-like flow near the poles. This flow is totally inside the Sun. It is completely

unexpected, and cannot be seen at the surface."

Additionally, there are features similar to the Earth's tradewinds on the surface of the Sun. Stanford researchers Schou and Dr. Alexander G. Kosovichev have found that there are belts in the northern and southern hemispheres where currents flow at different speeds relative to each other. Six of these gaseous bands move slightly faster than the material surrounding them. The solar belts are more than 65 000 km across and contain 'winds' that move at about 15 km per hour relative to their surroundings. The Stanford researchers have shown that, rather than being superficial surface motion, these belts extend down to a depth of at least 20 000 km below the Sun's surface.

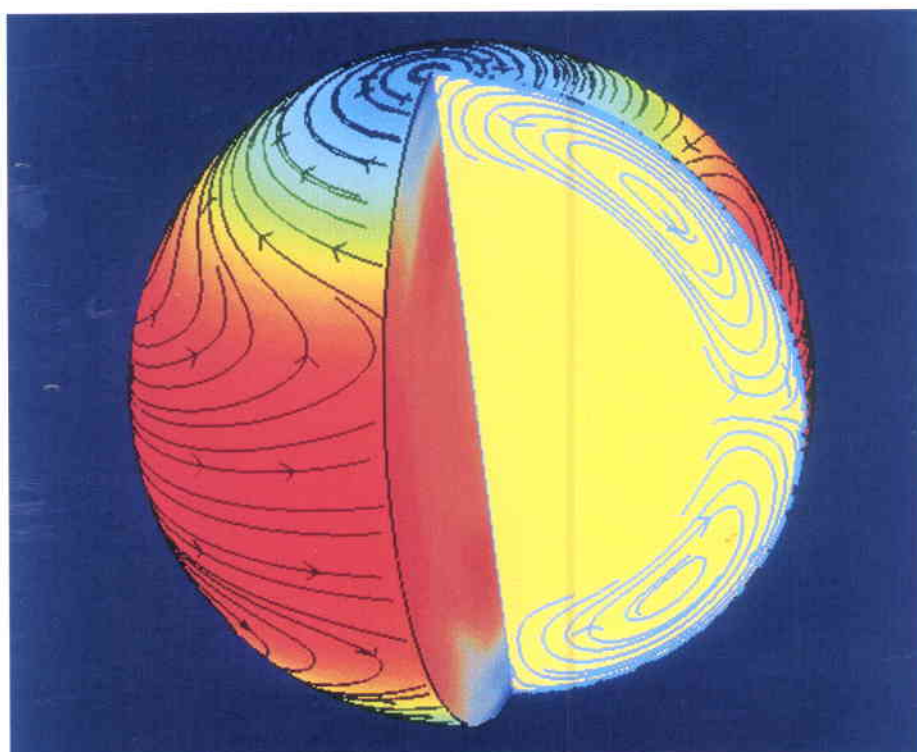
"In one way, the Sun's zonal belts behave more like the colourful banding found on Jupiter rather than the region of tradewinds on the Earth," said Stanford's Dr. Craig DeForest. "Somewhat like stripes on a barber pole, they start in the mid-latitudes and gradually move toward the equator during the eleven year solar cycle. They also appear to have a relationship to sunspot formation as sunspots tend to form at the edges of these zones".

The SOHO investigators have also determined that the entire outer layer of the Sun, to a depth of at least 25 000 km, is slowly but steadily flowing from the equator to the poles. The polar flow-rate is relatively slow, about 80 km per hour, compared to its rotation speed, about 6000 km/h; however, this is fast enough to transport an object from the equator to the pole in a bit more than a year. Evidence for polar flow had previously been observed at the Sun's surface, but scientists did not know how deep the motion extended.

"At this point, we do not know whether the plasma streams snake around like the jet stream on Earth, or whether it is a less dynamic feature," said Prof. Douglas Gough, of Cambridge University, UK. "It is intriguing to speculate that these streams may affect solar weather like the terrestrial jet stream impacts weather patterns on Earth, but this is completely unclear right now. The same speculation may apply to the other flows we've observed, or they may act in concert. It will be especially helpful to make observations as the Sun enters its next active cycle, expected to peak around the year 2001."

In Brief

Graphical representation of the surface flow from the equator to the poles of the Sun. The flow lines overlay an image of the rotation speed at the Sun's surface. The false colours represent speed; red material is rotating faster than the blue material. The lines represent how this motion would appear if you could stand on the surface of the Sun about 30 degrees from the equator. The cutaway on the right of the image represents the observed polar flow beneath the surface and return flow from the poles to the equator (photo courtesy of Stanford University)



Ariane V98 and V99 Successful

Ariane V98, a 44P version launcher, lifted off from Kourou (French Guiana) on 8 August at 03:46 Kourou time 06:46 GMT), carrying the PAS-6 satellite for the US company PanAmSat into geostationary transfer orbit.

The satellite weighed 3420 kg at lift-off and is equipped with 36 100 watt Ku-band transponders. It will provide digital direct broadcast TV coverage to all of South America, in particular Brazil.

The 99th Ariane launch (V99) took place on Tuesday 2 September at 19:21 Kourou time, 22:21 GMT). The 44 LP version launcher placed the telecommunications satellite HOTBIRD 3 (Eutelsat) and the meteorological satellite Meteosat-7 (Eumetsat) into geostationary transfer orbit.



100th Ariane Launch

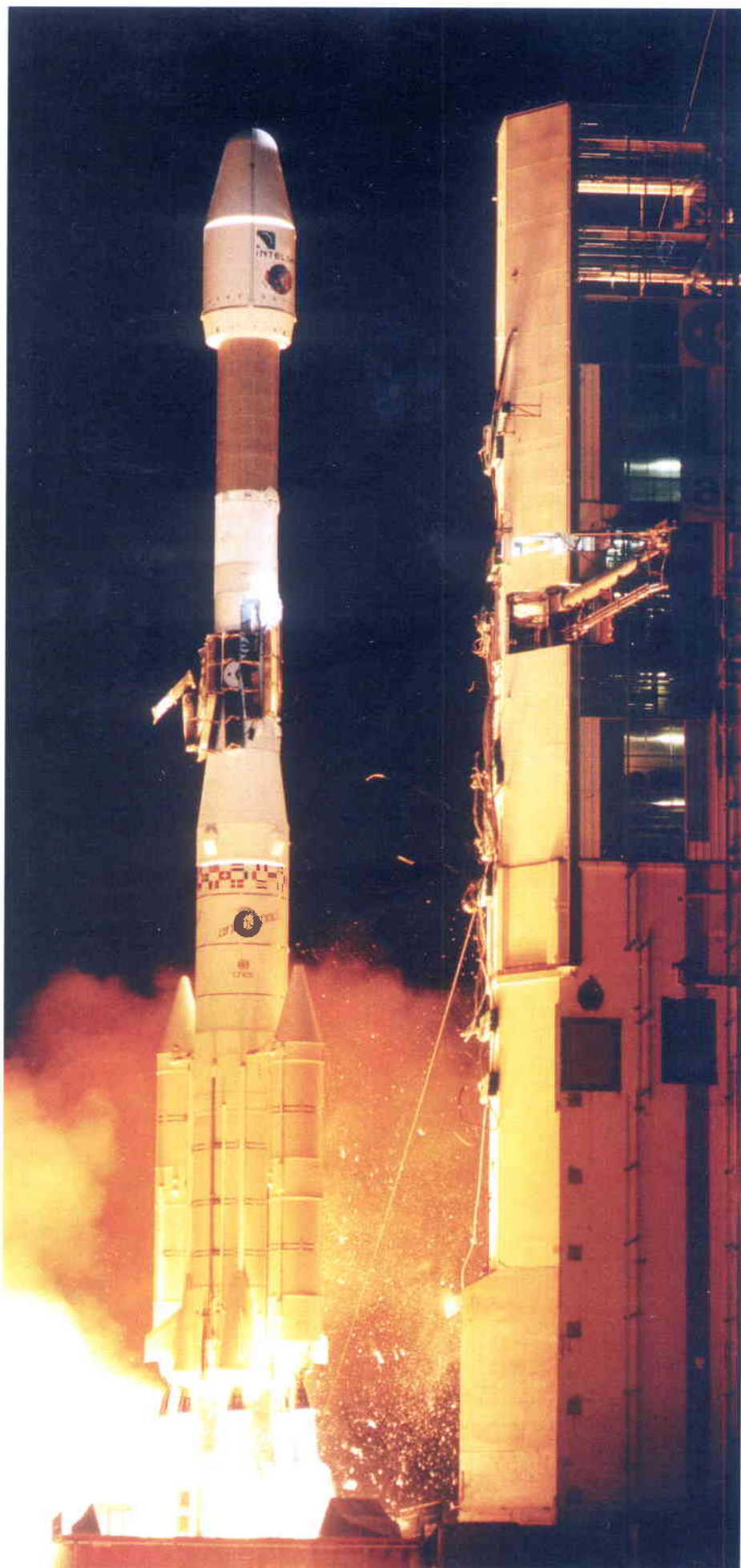
The 100th Ariane launch (V100) took place successfully on Tuesday 23 September.

An Ariane 42L version launcher (equipped with 2 liquid strap-on boosters) lifted off from the Guiana Space Centre at 20:58 Kourou time (23:58 GMT) and placed Intelsat 803 into geostationary transfer orbit.

Provisional parameters at third-stage injection into geostationary transfer orbit were:

- Perigee: 249.4 km (± 3 km) for a target of 250 km
- Apogee: 35 965 km (± 150 km) for a target of 35 959 km
- Inclination: 7.00 degrees (± 0.06 degrees) for a target of 6.99 degrees.

Flight 100 represented a major milestone for Europe, reflecting a record for successful launches: 40 satellites placed into orbit by 29 launches in the last 30 months.



17 “Ariane’s” salute the 100th Ariane

On the occasion of the 100th Ariane launch, ESA Public Relations decided to commemorate the successful launcher programme in a unique and memorable way.

Since the Ariane programme has been the result of a fruitful European cooperation, it was proposed to locate other European “Ariane’s” to participate in the ‘anniversary’ celebration. Various media organisations* within the ESA Member States supported the effort by initiating a search for young ladies with the name Ariane and born on or around Christmas Eve, 1979.

*Le Matin & Die Weltwoche (CH), Radio Nacional (E), Le Soir & BRT (B), Wouters Wondere Wereld - Veronica TV (NL), YLE-Finnish Broadcasting Corporation (FIN), die Presse (A), BBC/Newsround (UK), Radio Telefís Éireann (IRL), Göteborgs Posten (S), La Repubblica (I), France Info (F), Süddeutsche Rundfunk (D)

Though not an easy task - Ariane is not a common first name in many of the Member States - 16 young ladies in 12 countries were finally selected based on name and/or birth date. Additionally, the Guiana Space Centre in Kourou invited one extra Ariane. Therefore, a group of 17 young ladies departed for Kourou on Sunday, 21 September.

In Kourou, the “Ariane’s” were joined by 50 of the staff who had contributed to the success of the first launch and participated in the development of the Ariane programme. Together they witnessed the 100th launch into a clear evening sky through to the separation of the second stage.

With their participation and the help of the media, ESA hopes to have given the public in each of the Member States the opportunity to discover or re-discover the programme, which after 18 years is still a symbol of spectacular success for the European space effort.



The 17 “Ariane’s” in front of the new Ariane-5 launcher at the Guiana Space Centre.

Back row, left to right: Ariane Testuz (CH), Ariana Garcia (E), Ariadna Garcia-Castany (E), Ariana Bauwens (B), Ariane Dekking (NL), Mari Tapiola (FIN), Ariadne van den Bavière (B), Ariane Schoisswohl (A), Ariane Girouard (invited by CSG), Ariane Newlands (UK), Ariane Brophy (IRL).

Front row, left to right: Ariane Nordmann (CH), Christine Bokedal (S), Arianna Curci (I), Ariane Martin (F), Ariane Oligschläger (F), Ariane Soffned (D)



Reiter Qualifies as Soyuz Return Commander

On 24 July 1997, ESA astronaut Thomas Reiter was awarded with the Russian 'Soyuz Return Commander Certificate' at the Yuri Gagarin Cosmonaut Training Centre in Star City near Moscow. He is the first non-Russian astronaut to have earned this certificate which qualifies him to command the three-person Soyuz capsule during its return from space.

The Soyuz is currently used to transport astronauts to and from the Russian space station Mir and will be the main emergency vehicle for astronauts onboard the International Space Station. With Thomas Reiter's new certification, ESA can provide an astronaut qualified to return such a rescue vehicle. The knowledge acquired during his training also provides ESA with valuable input for the European Crew Transport/Crew Rescue Vehicle (CTV/CRV).

Thomas Reiter is no stranger to Russian space systems: he spent 179 days on



ESA astronauts, T. Reiter and C. Fuglesang during a training session in the Soyuz capsule simulator

board the Russian space station Mir in 1995/96 as part of the joint ESA-Russian Euromir 95 mission. During that time, he also performed two Extra Vehicular Activities (EVAs) or 'spacewalks'. To obtain this latest certification, he has completed an in depth course (600 hours) on the Soyuz-TM spacecraft systems which included numerous practical sessions in the Soyuz simulator. He has also undergone a number of oral examinations

given by Russian commissions. Under an agreement between ESA and the German Air Force, Thomas Reiter will now return to the German Air Force for an 18-month period to further his piloting and commander skills. Throughout this time, he will remain available to ESA for specific projects. He will resume his activities at ESA's European Astronauts Centre in March 1999, in preparation for a new assignment to a space mission.



ISU Studies Technology Transfer & Mission to Mars

'Technology Transfer' and 'Strategies for the Exploration of Mars' were the design projects assigned to the 96 students from 25 nations who attended this year's International Space University (ISU) Summer Session hosted by Rice University in Houston, Texas (in collaboration with NASA Johnson Space Center), from 7 June - 15 August.

Inaugurated at the Massachusetts Institute of Technology (MIT) in 1988, this marked the programme's 10th anniversary. In line with the founders' intention of creating a truly international institution, independent of national or commercial constraints, the ISU Summer Session has been held at a different university around the world each year and now has nearly 1200 international alumni.

The ISU Summer Session is an intensive 10-week programme for post-graduate students and young professionals of all

disciplines related to the space sector. During the course, students are exposed to over a dozen academic or research topics including Space Systems Architecture and Mission Design, Space Business and Management, Space Engineering, Space Life Sciences, Space Policy and Law, Space Resources, Robotics & Manufacturing, Satellite Applications, Space Physical Sciences, Space Informatics and Space & Society. Each year, ESA sends a group of European students to the ISU summer course. This year, 14 scholarships were awarded to students from the Agency's 14 Member States in addition to the six ESA staff selected to attend. ESA has also contributed faculty members, design project co-chairs and visiting lecturers.

In the concluding Design Project phase of the Summer Session, students work together to produce a complete conceptual design of an international space project and/or programme which covers all technical, financial, organisational and policy aspects. This element of the Summer Session provides students with the opportunity to put into

practice what they have learned in the lectures, workshops and other presentations and allows them to experience top-level decision-making processes in a truly multinational and interdisciplinary environment.

Previous ISU Summer Sessions have been held at the following locations:

- 1988: Massachusetts Institute of Technology (MIT), Cambridge, Massachusetts, USA
- 1989: Université Louis Pasteur (ULP), Strasbourg, France
- 1990: Institute for Space and Terrestrial Sciences (ISTS), Toronto, Canada
- 1991: Ecole Nationale de l'Aviation Civile (ENAC), FIAS, Toulouse, France
- 1992: City of Kitakyushu, Japan
- 1993: University of Alabama in Huntsville (UAH), Huntsville, Alabama, USA
- 1994: Universitat Autònoma de Barcelona (UAB), Barcelona, Spain
- 1995: Royal Institute of Technology (KTH), Stockholm, Sweden
- 1996: Austrian Society for Aerospace Medicine (ASM), Vienna, Austria



This year's ISU Summer Session was hosted by Rice University in Houston, Texas.

One of the two projects developed this year focused on 'Technology Transfer' and investigated strategies, policies and methods to improve the transfer of technologies developed and used by the space sector to other sectors such as medicine, transport or environmental applications. The second design project, called 'Strategies for the Exploration of Mars' was based on the development of a coherent and coordinated set of strategies and associated infrastructure elements (scientific and environmental data acquisition, data-relay infrastructure, space transportation systems, operational resources, etc.) for the international robotic and eventual human exploration of Mars over the next 25 years.

The International Space University is a non-profit, educational institution specialising in multidisciplinary, advanced space studies programmes. Since 1994, the ISU has been based in Strasbourg, France, where it permanently offers an 11-month Master of Space Studies programme.

For further information on the ISU, contact the Strasbourg Central Campus (tel: +33.3.88.65.54.30, fax: +33.3.88.65.54.47, e-mail: admissions@isu.isunet.edu) or the Education Office of ESA's Personnel Department (tel: +33.1.53.69.73.60, fax: +33.1.53.69.76.59, e-mail: maileduc@hq.esa.fr). You can also visit ISU's web site at <http://www.isunet.edu>.



ISO finds Fluoride Molecules in Interstellar Space

Using ESA's Infrared Space Observatory satellite, ISO, a team of astronomers from Germany and the United States has discovered trace amounts of hydrogen fluoride gas in the near vacuum of interstellar space.

Although approximately one hundred different kinds of molecules have been detected in interstellar space over the past 30 years, the discovery of hydrogen fluoride marks the first time that a molecule containing fluorine has been detected in an interstellar gas cloud.

The observations were carried within a giant cloud of interstellar gas located near the centre of the Milky Way galaxy using the Long Wavelength Spectrometer, one of four instruments on board ISO. Looking in the far-infrared region of the electromagnetic spectrum, the astronomers observed the telltale signature of absorption by trace amounts of hydrogen fluoride gas.

"Because the Earth's atmosphere is completely opaque to far-infrared radiation, the observations that we carried out are possible only from space," said Professor David Neufeld of the Department of Physics and Astronomy, Johns Hopkins University, Baltimore, leader of the team that reported the finding. "The ISO satellite has opened up an exciting new window on the Universe by allowing us to observe at far-infrared wavelengths." The characteristic wavelength at which hydrogen fluoride molecules absorb radiation is approximately one eighth of a

millimetre, much larger than the wavelength of visible light but much smaller than the wavelengths typically used for radio and television communications. In concentrated liquid form, hydrogen fluoride — or hydrofluoric acid as it is known when dissolved in water — is familiar to laboratory chemists as an extremely dangerous and corrosive acid that dissolves glass and severely burns human tissue. The gas cloud in which hydrogen fluoride molecules were discovered lies approximately 20 000 light years from Earth, in the southern constellation Sagittarius. Known to astronomers as Sagittarius B2, the gas cloud is composed primarily of hydrogen molecules. As in other clouds of interstellar gas, the environment in Sagittarius B2 is very extreme by terrestrial standards, with temperatures less than minus 220 Celsius, and pressures more than one hundred million times smaller than the atmospheric pressure on Earth. Although the hydrogen fluoride is less than one thousand millionth as abundant as the hydrogen, the sensitivity of the ISO spectrometers made its detection possible.

"This discovery gives us the opportunity to study the chemistry of fluoride molecules in the frigid conditions that characterise the near vacuum of interstellar space," says Neufeld. "One of the key questions is how these molecules were formed. Our analysis suggests that the hydrogen fluoride we detected was produced by direct chemical reactions between fluorine atoms and hydrogen molecules. Unlike most atoms, fluorine atoms are extremely reactive and attack the relatively inert hydrogen molecules that are the principal constituent of the interstellar gas. The result is hydrogen fluoride."



ESOC Celebrates 30th Anniversary

On 8 September, the European Space Operations Centre (ESOC) celebrated its 30th year of service as ESA's satellite control centre. Joining in the celebration were ESOC staff members and contractors, the ESA Management Board, two former ESOC Directors, as well as retired ESA staff and guests.

ESOC, formerly the European Space Data Centre (ESDAC) under the European Space Research Organisation (ESRO), was established in September 1967 in Darmstadt, Germany. By May 1968 it was fully operational and ready to take over responsibility for the operation of ESRO 2B. Since then, ESOC has been responsible for the operation of over thirty-five spacecraft missions for ESA and later for Eutelsat, Eumetsat and Inmarsat. It has also provided support to eighteen satellites built for various national agencies and administrations. Thanks to advanced technology, ESOC is able to control over fifteen satellites in parallel. It is presently controlling seven satellites from Darmstadt and the associated control centres.

ESOC is also at the forefront of research into orbital debris and coordinates the European effort in this domain. It maintains



The ESA Management Board gathered at ESOC on the occasion of the 30th Anniversary celebration. Back row, left to right: M. Trella (IG), F. Roscian (H/ESRIN), K.-E. Reuter (H/CAB), B. Walker (AD/S), J.-J. Dordain (AD/ISP), H. Kappler (D/IMTP). Front row, left to right: J. Feustel-Büechl (D/MSM), R. Bonnet (D/SCI), A. Rodotà (DG), D. Dale (D/TOS), D. Sacotte (D/A), F. Engström (D/L). Not in photo: R. Collette (D/APP)

the DISCOS Database & Information System which has characterised more than 2.1 million orbital elements. Around 25 000 objects are added monthly. Further information regarding ESOC operations support can be found at <http://www.esoc.esa.de>



Space Telescope Helps European Astronomers Study Major Transitions in Early Universe

Observations of the bright southern quasar HE 2347-4342 using European Space Observatory (ESO) telescopes and the NASA/ESA Hubble Space Telescope (HST), have provided a group of European astronomers with an exceptional glimpse into an early, still unexplored, transition period of the Universe.

At that time, many billions of years ago, some of the enormous gaseous clouds of hydrogen and helium left over from the Big Bang had not yet been fully ionised by the increasingly strong radiation from emerging galaxies and stars. In recent years astronomers have successfully 'looked back' on this period, but the new observations of HE 2347-4342 have homed in on an important transitional epoch during the evolution of the young Universe.

After many years of careful preparatory work, Dieter Reimers and his colleagues at the University of Hamburg (D) have identified two bright and distant quasars whose light reaches us along relatively

The ESOC choir entertains staff and guests with songs by Andrew Lloyd Webber.



unobstructed paths, and which are sufficiently distant to observe intergalactic helium in their lines of sight (only four such quasars are presently known). The very brightest of these (1015 times more luminous than our Sun) is the quasar HE 2347-4342 in the southern constellation of Phoenix. Its redshift is so high that a specific helium-line in the far-ultraviolet spectral region is shifted into a wavelength region that is observable. This places it at a distance which implies a 'look-back' in time of more than 80% of the age of the Universe. Thus we observe it as it was just a few billion years after the Big Bang.

The HST observations of HE 2347-4342 have therefore provided important information, not only about the quasar itself, but also about the conditions in the surrounding intergalactic medium at this early time. For example, one can observe, for the first time, the patchiness of the intergalactic matter at the exact time of this major transition phase in the Universe.

When, in June 1996, the Hubble Space Telescope was pointed towards this quasar, good-quality recordings of its ultraviolet spectrum were obtained during no less than 13 orbital periods. The observed line structure shows adjacent regions of both very high and low absorption — indicative of an intergalactic medium undergoing the final stage of re-ionisation. This first, direct observation of the late stages of the re-ionisation epoch is an important step forward in our understanding of the thermal history of



HST image of a small sky area in the southern constellation of Phoenix, around the newly discovered, unusually bright quasar HE 2347-4342 (redshift $z = 2.885$) seen at the very centre of the frame. (courtesy of ESO Online Digitized Sky Survey)

the Universe. Theoretical modelling based on such data should allow us to identify, more precisely, the still unknown epoch when the first galaxies and quasars began to light up and thereby to ionise the intergalactic gas left over from the Big Bang.

Observation of the re-ionisation epoch also provides yet another confirmation of standard Big Bang cosmology. 

Legal and Policy Aspects of Cooperation

An international colloquium was held on 11 and 12 September to discuss legal issues and future cooperation between ESA and Central and Eastern European Countries. Topics included:

- current frame cooperation agreements (legal analysis)
- Central and Eastern European viewpoints
- other institutional frameworks (European Union and Central European Initiative)
- Space Law.

Held in Prague, the colloquium was co-organised by the Czech Society of International Law (in association with the Faculty of Law, Charles University, Prague), ESA and the European Centre for Space Law. 

Mr Jean-Jacques Dordain of ESA handing over a SOHO model to Prof. E. Ondracek, Deputy Minister of Education, Youth and Sports of the Czech Republic



Pre-dawn Floridian skies lit up by the lift-off of the Cassini/Huygens mission as it started its seven-year journey to Saturn



Successful Launch of Cassini/Huygens Mission

ESA's latest and farthest venture into the Solar System began at 04:43 European Daylight Time (EDT), 10:43 Central European Time (CET), from Cape Canaveral, Florida, on 15 October.

About 500 representatives of the European scientific, engineering and industrial teams responsible for building the Huygens Probe, witnessed the powerful boosters of the Titan launcher light up the pre-dawn sky.

The Cassini/Huygens launch sequence concluded with the completion of the second firing and separation of the Centaur upper stage rocket at 05:26 EDT. NASA's ground station at Canberra, Australia, obtained good signals from Cassini an hour after launch.

The European Space Operations Centre (ESOC) at Darmstadt will monitor the condition of the Huygens spacecraft throughout its seven-year journey.

The next major event will be the swing-by of Cassini/Huygens at Venus on 21 April 1998. This will be the first of a sequence of 'gravity-assist' operations at Venus, the Earth and Jupiter, used to accelerate the spacecraft.

In 2004, the Huygens probe will plunge into the thick atmosphere of Saturn's largest moon, Titan.



The AWARDS Project

On Friday 26 September 1997, the Agency held the kick-off meeting in ESRIN for Phase 2 (the Development Phase) of its AWARDS Project. AWARDS is the title of the ESA project to replace its long-standing Financial System, EFSY. The Agency has adopted a new approach to its financial management by replacing EFSY, a custom-made product now some fourteen years old, with a COTS (commercial off-the-shelf) financial package.

A feasibility study of this new approach started in April 1995 and culminated in the selection of GEAC's SmartStream Financials in mid-1996 to form the basis of the Agency's new financial system, AWARDS, as from January 1999.

Phase 1 (the Definition Phase) started in August 1996 and was completed one year later. With a mandate to adopt general financial practices as covered by SmartStream Financials, as far as the Agency's financial regulations will allow, significant simplifications in the Agency's operating procedures are anticipated. Furthermore, the advanced technology of the SmartStream product will provide easy access to non-Finance authorised users and, additionally, enable the establishment of interfaces to both Programme and Administrative systems. This will result in a two-way flow of information of mutual benefit.



ESA Finance and Technical staff who will be immediately involved in the development of the AWARDS operational software and their counterparts from Industry who will be responsible for its production. The Prime Contractor is CAP GEMINI (F) with AXYS (F) as principal sub-contractor

The ESA Project Manager, Mr C.W. Pridgeon (seated centre) shaking hands with Mr J.-P. Gleyse of CAP GEMINI after the executive order for Phase 2 was signed by both parties. Also pictured are (standing, left to right) Mr P. Escande, CAP GEMINI, Mr E. Schreyers, ESA AWARDS Technical Manager, and (seated right) Mr T. Beer, ESA Contracts Officer responsible for AWARDS

First Automatic Parafoil Flight Test

On 25 June 1997, the first automatically-guided, parafoil-based descent and landing of a test vehicle was carried out in support of ESA's development of a Crew Transfer Vehicle (CTV) that will travel to and from the International Space Station.

The flight test is part of ESA's Parafoil Technology Demonstration (PTD) programme through which landing techniques for the planned CTV are being validated. A large parafoil is used to slow down the craft's velocity and allow it to make a precise landing on unprepared terrain. The system has been qualified for payloads of up to 3200 kg through 10 previous flight tests, including three remotely controlled flights performed in April and May 1997.

This latest, automatically-guided test was performed in Germany using a large parafoil (160 m²) with a payload of more than 1700 kg. The vehicle's guidance system was based on GPS (Global Positioning System) navigation.

The test vehicle, which includes actuators and avionics equipment to control flight, as well as a sensor package and a telemetry/telecommand capability, was released from a transport aircraft at an altitude of 1800 m. The opening sequence of the parafoil and the subsequent glide were normal. Following the check-out of all systems, the automatic guidance of the test vehicle was self-initiated and the touchdown was within 200 m of the planned landing area. The landing loads were reduced to a minimum by means of a dynamic flare manoeuvre.

Major elements of ESA's parafoil-based descent and landing system are considered to be excellent candidates for the X-38 programme orbital flight tests, a first step in ESA's cooperation with NASA to develop a family of crew return and transfer vehicles.

Daimler-Benz Aerospace in Munich (D) is the prime contractor for the development and flight testing of the parafoil system, primarily supported by Aerazur (F), Dassault (F), Fokker Space (NL) and APCO (CH).



A test vehicle makes the first automatically-guided, parafoil-based descent and landing as part of ESA's Parafoil Technology Demonstration programme through which soft and accurate landing techniques for the planned Crew Transfer Vehicle (CTV) are being validated. ESA is studying a CTV for the transport of international crew to and from the International Space Station (photo courtesy of ESA-Daimler-Benz Aerospace)

ESA Invention Flies on Inmarsat-3 Satellites

One of the key objectives of ESA's R&D activities is to enhance the ability of the European space industry to compete on world markets. This goal has been fulfilled in the case of the Inmarsat-3 communication satellite series, for which European industry won the payload procurement contract.

Matra Marconi Space has delivered five communication payloads to Lockheed Martin for the Inmarsat-3 satellites, four of which have been successfully launched since April 1996, the last on 3 June 1997 from Kourou by an Ariane 44L launcher (V97). These payloads generate a set of L-band spot beams for world-wide voice and data communication services to mobile terminals on ships, aircraft and vehicles, as well as small pocket-size messaging units. They use the latest spot-beam technology providing power-efficient dynamic allocation of communication traffic to the various

beams, and allowing greater re-use of the available frequency spectrum. This efficient spot-beam technology relies on a novel antenna front-end invented by ESA's Dr Antoine Roederer and licensed by the Agency to Matra Marconi Space.

With this semi-active antenna architecture, the excitation of the radiators feeding the reflector can be varied so as to reconfigure the spot-beam coverage, while keeping amplifier power levels virtually constant. This results in optimum DC to RF power conversion efficiency for the payload, thereby maximising satellite channel capacity.

According to Inmarsat, the operational in-flight performance of the antenna has exceeded expectations. The novel ESA technology has been recognised as being outstandingly efficient, in terms of both flexibility and power consumption, and is being adopted for world-wide use in the next generation of geostationary personal communication satellites.



Inmarsat-3 satellite model undergoing antenna tests (photo courtesy of Matra Marconi Space)

48th IAF Congress

Developing Business from Space was the central theme of this year's congress organised by the International Astronautics Federation (IAF), the International Academy of Astronautics (IAA) and the International Institute of Space Law (IISL) from 6-10 October. The congress was held in Turin, Italy, the centre of Italian domestic and international space activities. As a major international event, the congress attracted 1400 participants and presenters representing major space agencies around the world. In keeping with the theme, the congress also provided opportunities for space agencies and industry to sign agreements for future services (see photo).

The opening ceremony was visited by a number of national and international officials, including the President of the Italian Republic, Oscar Luigi Scalfaro. The city of Turin opened its doors to all participants, sponsoring a reception and concert of Italian Baroque music as well as visits to its many museums.

An International Exhibition dedicated to Transfer of Technology highlighted the most significant aspects of the transfer of space technology to other fields such as the automobile industry, energy generation, sensors, biotechnology and medicine.

The public's interest and enthusiasm for space activities was demonstrated by the some 65 000 visitors to the week-long events and exhibitions.



On October 7, during the IAF Congress, Mr Antonio Rodotà (seated, left), ESA's Director General, and Dr Conrado Varotto (seated, right), President of the Comisión Nacional de Actividades Espaciales of Argentina (CONAE), signed an agreement between ESA and CONAE concerning the direct reception, archiving, processing and distribution of ERS-1/2 SAR data. The signing was assisted by Mr Marco Ferrazzani (standing, left), ESA Legal Affairs, and Mr Karl-Egon Reuter (standing, right), ESA Head of Cabinet

ESA and NASDA Exchange Hardware

ESA recently signed a Memorandum of Understanding (MOU) with the National Space Agency of Japan (NASDA) agreeing to exchange hardware to be used on the International Space Station (ISS), along with the required support services.

The MOU, signed on 5 November in Paris which, for the first time, does not involve the exchange of funds. According to the terms of agreement, ESA will deliver to NASDA one flight unit of a Minus Eighty

Degree Laboratory Freezer (MELFI). In return, NASDA will provide ESA with 12 flight-unit International Standard Payload Racks (ISPRs). Both exchanges include associated support equipment and training.

The MELFI facility will be used to store scientific experiment samples at a very low temperature (-80°C) both on board the ISS and during transportation on the US Space Shuttle. The freezer is currently under development by a European consortium led by Matra Marconi Space (see In Brief, Bulletin 89) and is to be delivered to NASDA by the second half of 1999. ESA will also deliver three identical freezers to NASA under a separate ESA/NASA agreement.

The ISPR is a rack accommodating laboratory facilities and experiments to, and on board, the ISS. The structure and its interfaces with Space Station modules are based on a concept that has been agreed by the ISS partners and increases commonality in ISS utilisation support equipment. Deliveries of the ISPRs are scheduled for November 1997 and March 1999.

"Through this exchange of hardware, we have been able to minimise our respective development and procurement costs. We have capitalised on existing industrial development activities in both Europe and Japan" noted J. Feustel-Büechl, ESA's Director of Manned Spaceflight and Microgravity.



Signing the MOU for the exchange of ISS hardware are (left to right, seated): Mr H. Murayama, Executive Director, Office of Space Utilisation Systems, NASDA and Mr J. Feustel-Büechl, ESA's Director of Manned Spaceflight and Microgravity

Focus Earth

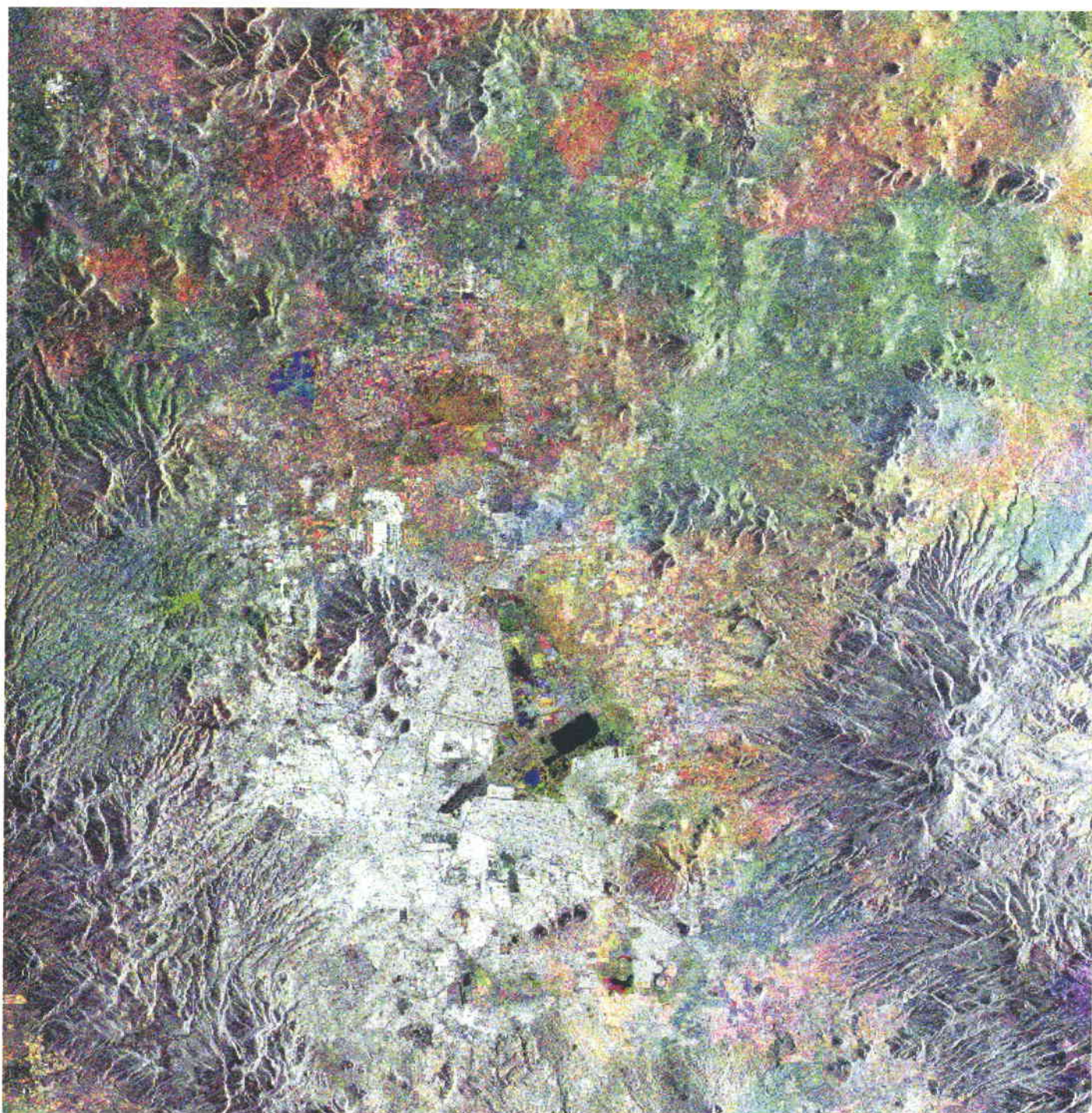
Mexico City

J. Lichtenegger, G. Calabresi & M. d'Amico

ESA/ESRIN, Frascati, Italy

This ERS SAR multi-temporal image is a composite of various acquisitions during the 1995-1997 time period. It provides an overview of Mexico D.F. and surroundings. Densely populated zones are displayed in white or in a bluish tone with white dots. Agricultural areas appear in reddish and yellow tones, and natural vegetation in green. Mexico City is visible in the central

lower left part of the image, which covers an area of 100 km by 100 km. City boundaries can be clearly distinguished, especially when they are marked by drainage channels. However, they become fuzzy towards the west and south, where the city sprawls into the hills of the Sierra del Ajusco. Because of the radar's illumination effect, some of the city

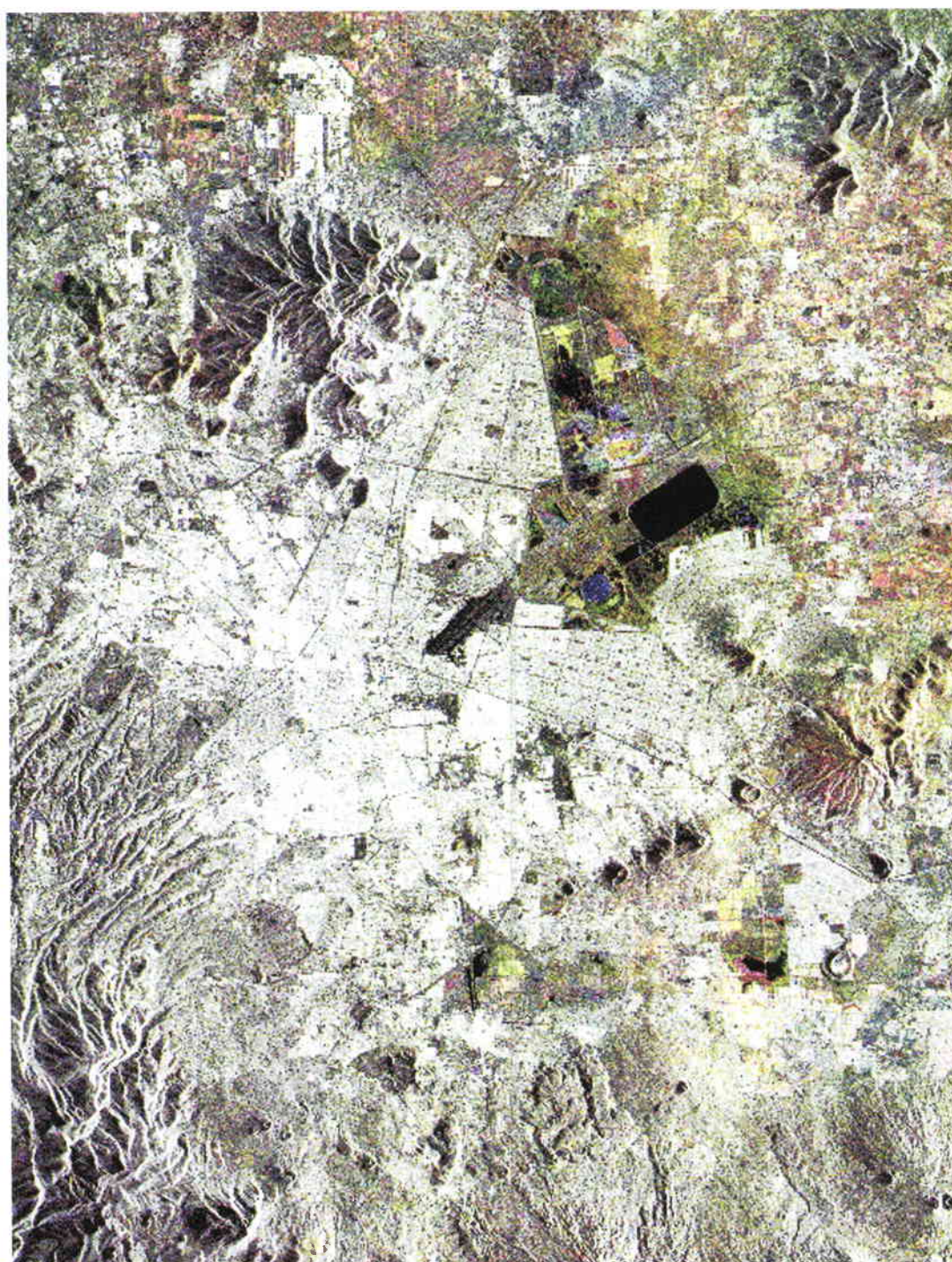


areas stand out in bright tones, with streets running parallel and perpendicular to the satellite track. Data from ERS SAR descending passes were used to derive this image; if data acquired from an ascending orbit were utilised, other areas would stand out instead. The various units that constitute the urban area can be mapped with the help of such information.

The imaged area extends from Tula in the top left to Amecameca in the lower right. Well-known places like Teotihuacan are difficult to pinpoint, but are still visible as bright points in the green area to the upper right, near the centre of the image. The morphology of the landscape can be well appreciated. It is characterised by huge volcanoes with radially cut valley slopes. The Sierra Nevada lies to the east (right of Mexico City), culminating in the 5452 m-high Popocatepetl

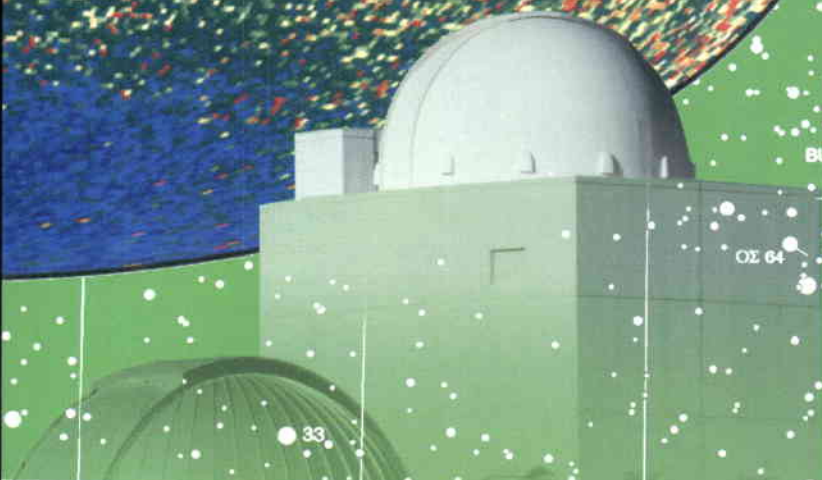
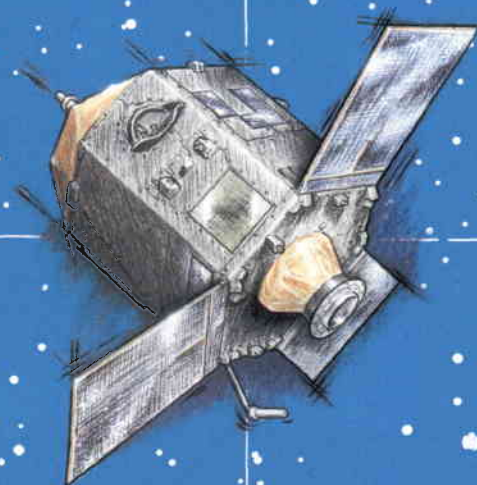
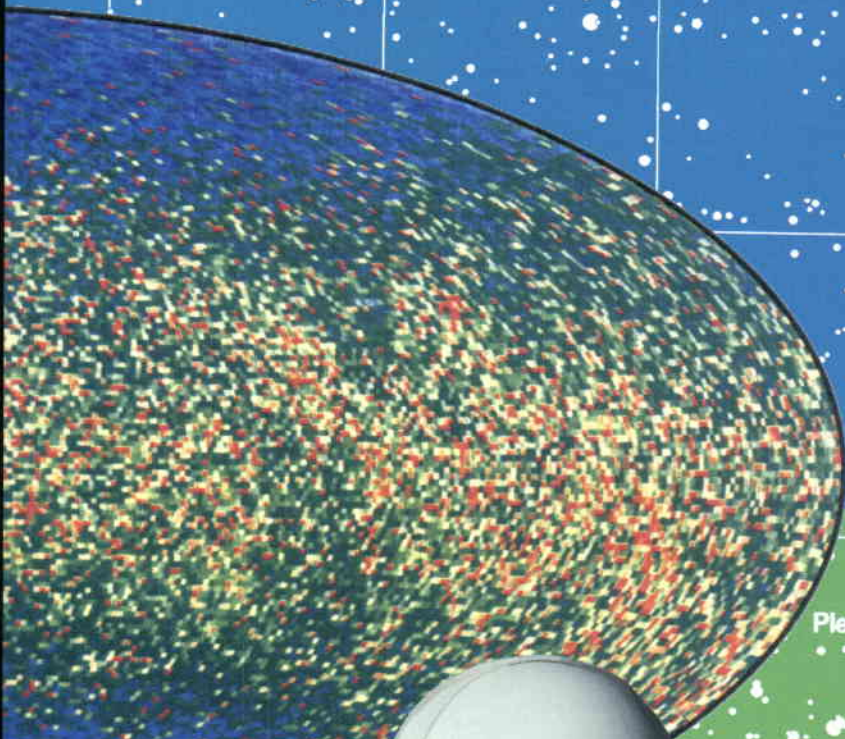
mountain (out of picture to the south-east). Part of its northern neighbour, the 5286 m-high Iztaccihuatl, is visible in the lower right corner. The magenta colour indicates that on one date of ERS SAR acquisition, i.e. 28 December 1995, it was snow-capped. Several, if not all, of the small hills apparent in the image are probably volcanic cones. However, because of the steep angle of incidence of the ERS radar, only those with more gentle slopes show the typical encircled volcanic rim or caldera.

The data to produce this image were acquired at the ERS receiving station in Norman, USA and processed by ESA/ESRIN in Frascati, Italy. The three dates of acquisition were: 19 September 1997 displayed in blue, 21 June 1996 displayed in red, and 28 December 1995 displayed in green.



The enlargement of part of Mexico City reveals some of its historical development, including the progressive shrinking of the Texcoco Lake, in the middle of which the Aztecs built Tenochtitlan. The remnants of this lake can be spotted in the northeastern part of the city, where a strange circular feature can be detected: it is a water evaporation plant of huge dimensions. The city seems to have expanded in a well-structured, the modular way towards east. Each one of the 'building blocks' has the traditional central 'plaza' but, especially in the south, their growth looks rather uncontrolled, as dwellings spread into the hills. Such behaviour can be monitored by spaceborne radar because of the strong backscatter produced, occasionally even from individual houses. 

The Hipparcos and Tycho Catalogues



Pleiades M45

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The Mission Products

The principal parts of the Hipparcos Catalogue are provided in both printed and machine-readable form. Tycho Catalogue results are provided in machine-readable form only. The printed volumes include a description of the Hipparcos and Tycho Catalogues and associated annexes, a description of the satellite operational phase, a description of the corresponding data analysis tasks, and the final data.

The definitive mission products are also released as a set of ASCII files on a series of CD-ROMs, which contain all of the printed catalogue information as well as some additional data. Auxiliary files containing results from intermediate stages of the data processing, of relevance for the more-specialised user, are also included.

The Hipparcos Mission

The Hipparcos space astrometry mission was accepted within the European Space Agency's scientific programme in 1980. The Hipparcos satellite was designed and constructed under ESA responsibility by a European industrial consortium led by Matra Marconi Space (France) and Alenia Spazio (Italy), and launched by Ariane-4 on 8 August 1989. High-quality scientific data were acquired between November 1989 and March 1993. The scientific aspects of the mission were undertaken by nationally-funded scientific institutes. All of the scientific goals motivating the mission's adoption in 1980 were surpassed, in terms of astrometric accuracy, photometry, and numbers of stars.

The global data analysis tasks, proceeding from nearly 1000 Gbit of satellite data to the final catalogues, were undertaken by three scientific consortia: the NDAC and FAST Consortia, together responsible for the production of the Hipparcos Catalogue; and the Tycho Consortium, responsible for the production of the Tycho Catalogue. A fourth scientific consortium, the INCA Consortium, was responsible for the construction of the Hipparcos observing programme. The production of the Hipparcos and Tycho Catalogues marks the formal end of the involvement in the mission by ESA and the four scientific consortia.

The Hipparcos and Tycho Catalogues

The final products of the European Space Agency's Hipparcos mission are two major stellar catalogues, the Hipparcos Catalogue and the Tycho Catalogue.

Each catalogue includes a large quantity of very high quality astrometric and photometric data. The astrometric data in the Hipparcos Catalogue is of unprecedented accuracy: positions at the catalogue epoch (J1991.25), annual proper motions, and trigonometric parallaxes, have a median accuracy of approximately 1 milliarcsec. The Hipparcos Catalogue includes annexes featuring variability and double/multiple star data for many thousands of stars discovered or measured by the satellite. The Hipparcos and Tycho Catalogues will remain the definitive astrometric stellar catalogues for many years.

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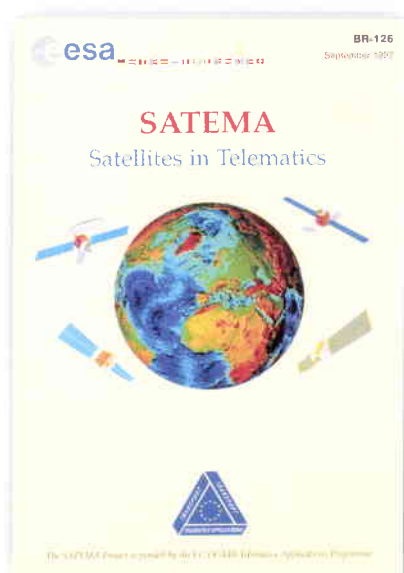
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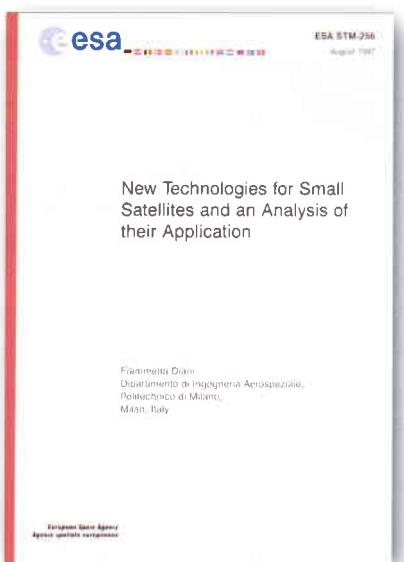
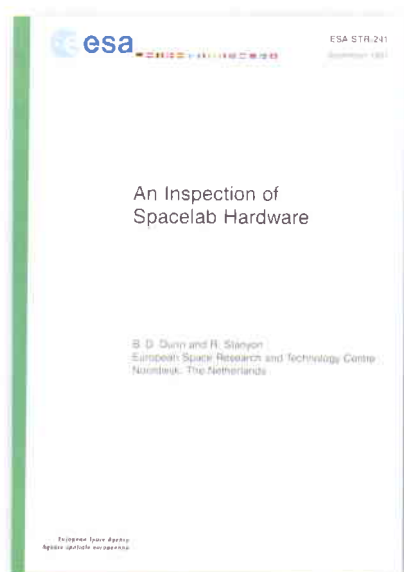
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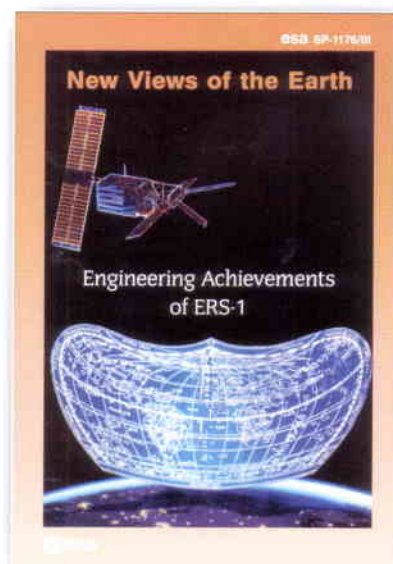
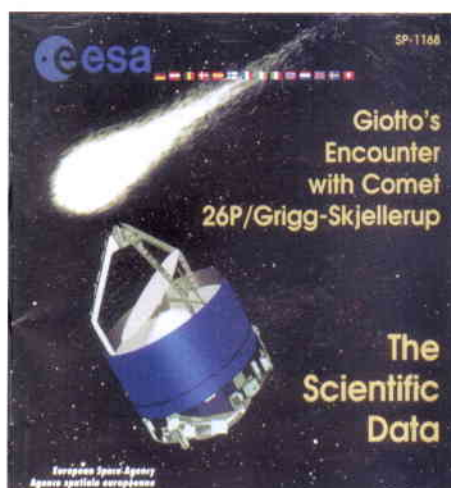
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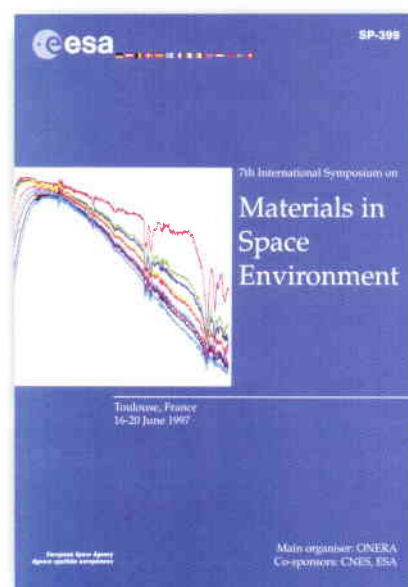
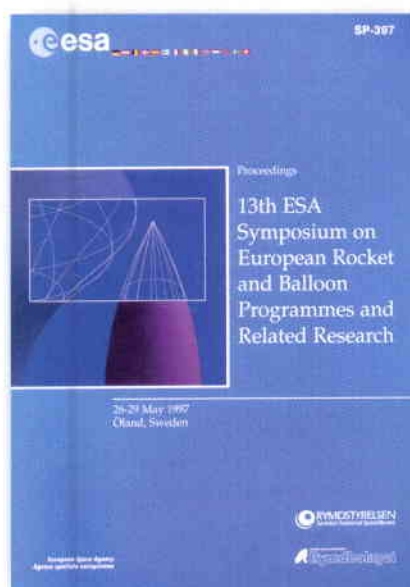
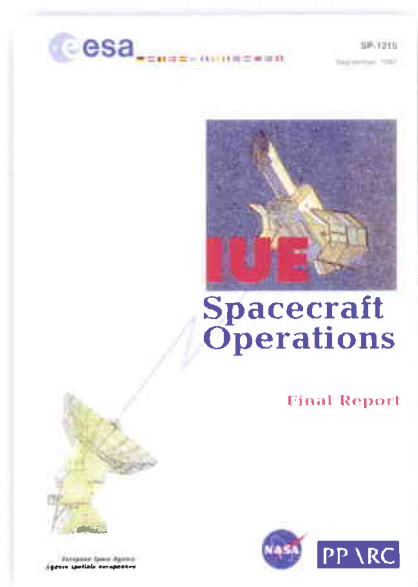
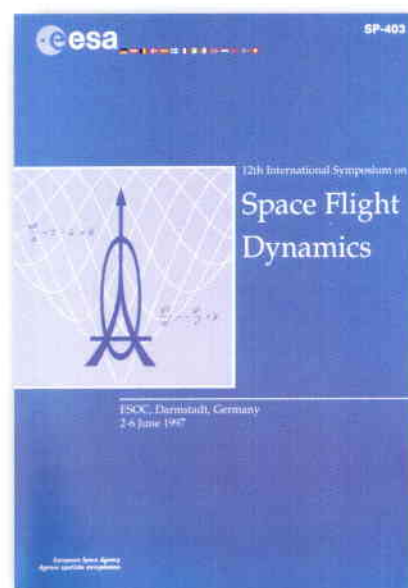
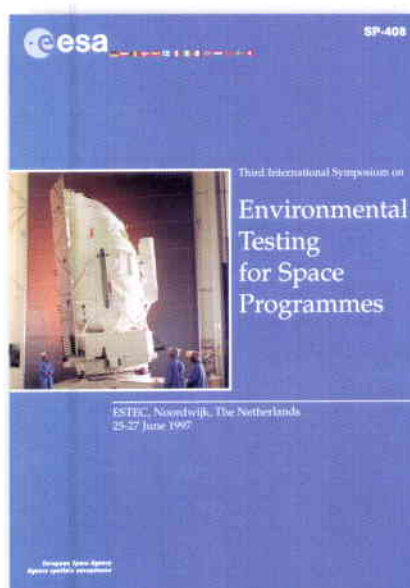
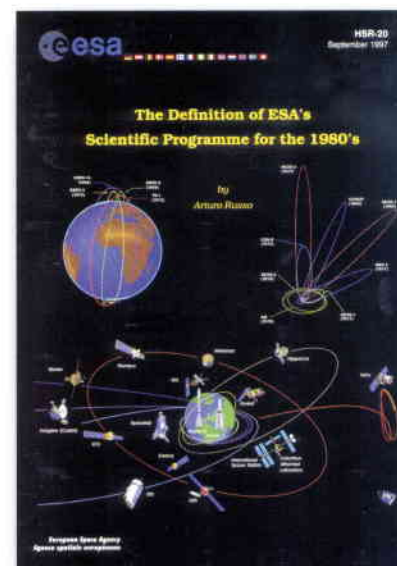
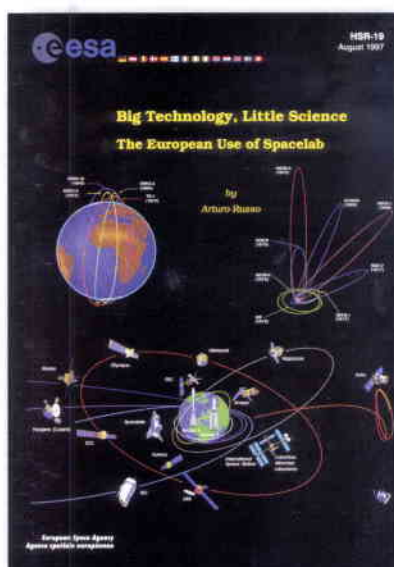
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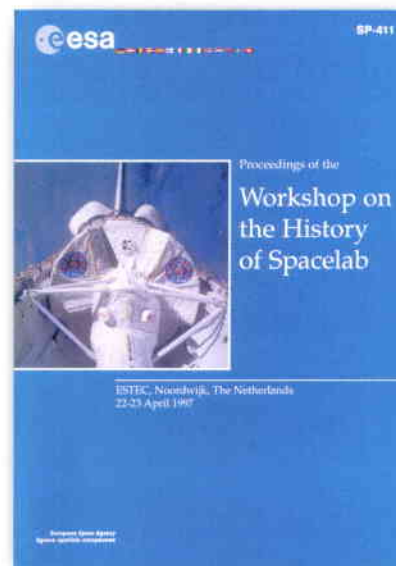
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