european space agency

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agence spatiale européenne

number 64

november 1990

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, France, Germany, Ireland, Italy, Netherlands, Norway, Spain, Sweden, Switzerland and the United Kingdom. Finland is an Associate Member of the Agency. 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.

The Directorate of the Agency consists of the Director General; the Inspector General; the Director of Scientific Programmes; the Director of Observation of the Earth and its Environment; the Director of the Telecommunications Programme; the Director of Space Transportation Systems; the Director of the Space Station and Microgravity Programme; the Director of ESTEC; the Director of Operations and the Director of Administration.

The ESA HEADQUARTERS are in Paris.

The major establishments of ESA are:

THE EUROPEAN SPACE RESEARCH AND TECHNOLOGY CENTRE (ESTEC), Noordwijk, Netherlands.

THE EUROPEAN SPACE OPERATIONS CENTRE (ESOC), Darmstadt, Germany

ESRIN, Frascati, Italy.

Chairman of the Council: Prof. F. Carassa

Director General: J.-M. Luton.

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 France, l'Irlande, l'Italie, la Norvège, les Pays-Bas, le Royaume-Uni, la Suède et la Suisse. La Finlande est membre associé de l'Agence. Le Canada beneficie d'un statut d'Etat coopérant.

Selon les termes de la Convention: l'Agence a pour mission d'assurer et de développer, à des fins exclusivement pacifiques, la coopération entre Etats européens dans les domaines de la recherche et de la technologie spatiales et de leurs applications spatiales, en vue de leur utilisation à des fins scientifiques et pour des systèmes spatiaux opérationnels d'applications:

(a) en élaborant et en mettant en oeuvre une politique spatiale européenne à long terme, en recommandant aux Etats membres des objectifs en matière spatiale et en concertant les politiques des Etats membres à l'égard d'autres organisations et institutions nationales et internationales;
(b) en élaborant et en mettant en oeuvre des activités et des programmes dans le domaine spatial;
(c) en coordonnant le programme spatial européen et les programmes nationaux, et en intégrant ces derniers progressivement et aussi complètement que possible dans le programme spatial européen, notamment en ce qui concerne le développement de satellites d'applications.
(d) en élaborant et en mettant en oeuvre la politique industrielle appropriée à son programme et en recommandant aux Etats membres une politique industrielle cohérente.

L'Agence est dirigée par un Conseil, composé de représentants des Etats membres. Le Directeur général est le fonctionnaire exécutif supérieur de l'Agence et la représente dans tous ses actes.

Le Directoire de l'Agence est composé du Directeur général; de l'Inspecteur général; du Directeur des Programmes scientifiques; du Directeur des Programmes d'Observation de la Terre et de son Environnement; du Directeur du Programme de Télécommunications; du Directeur des Systèmes de Transport spatial; du Directeur du Programme Station spatiale et Microgravité; du Directeur de l'ESTEC, du Directeur des Opérations et du Directeur de l'Administration.

Le SIEGE de l'Agence est à Paris.

Les principaux Etablissements de l'Agence sont:

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LE CENTRE EUROPEEN D'OPERATIONS SPATIALES (ESOC), Darmstadt, Allemagne.

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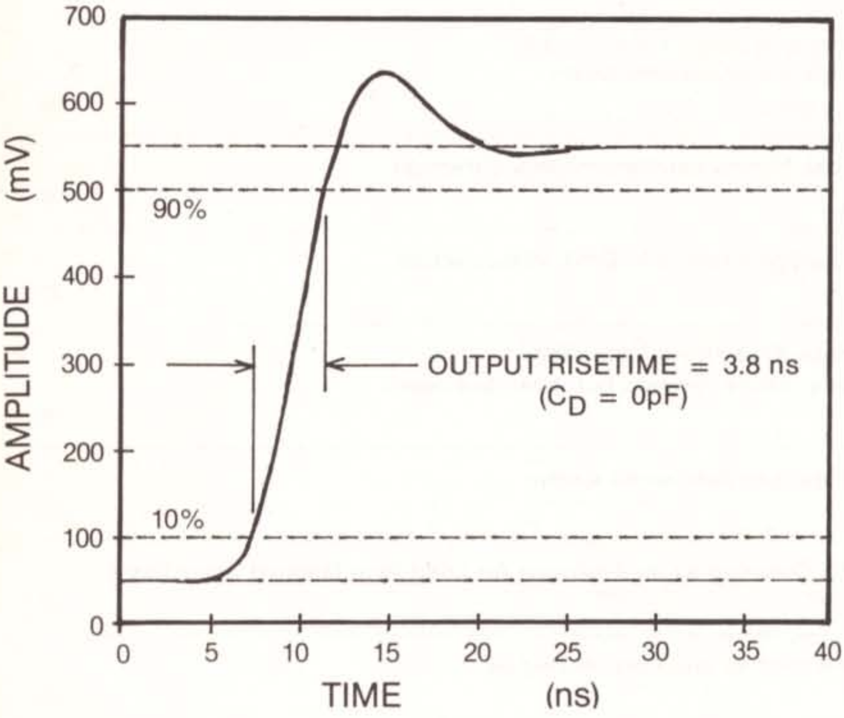
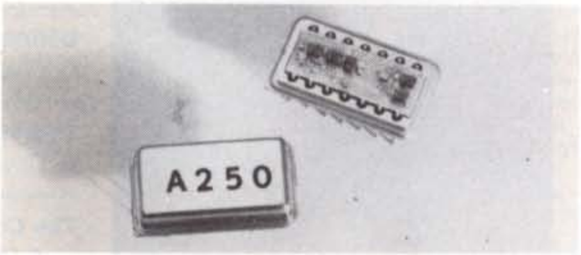


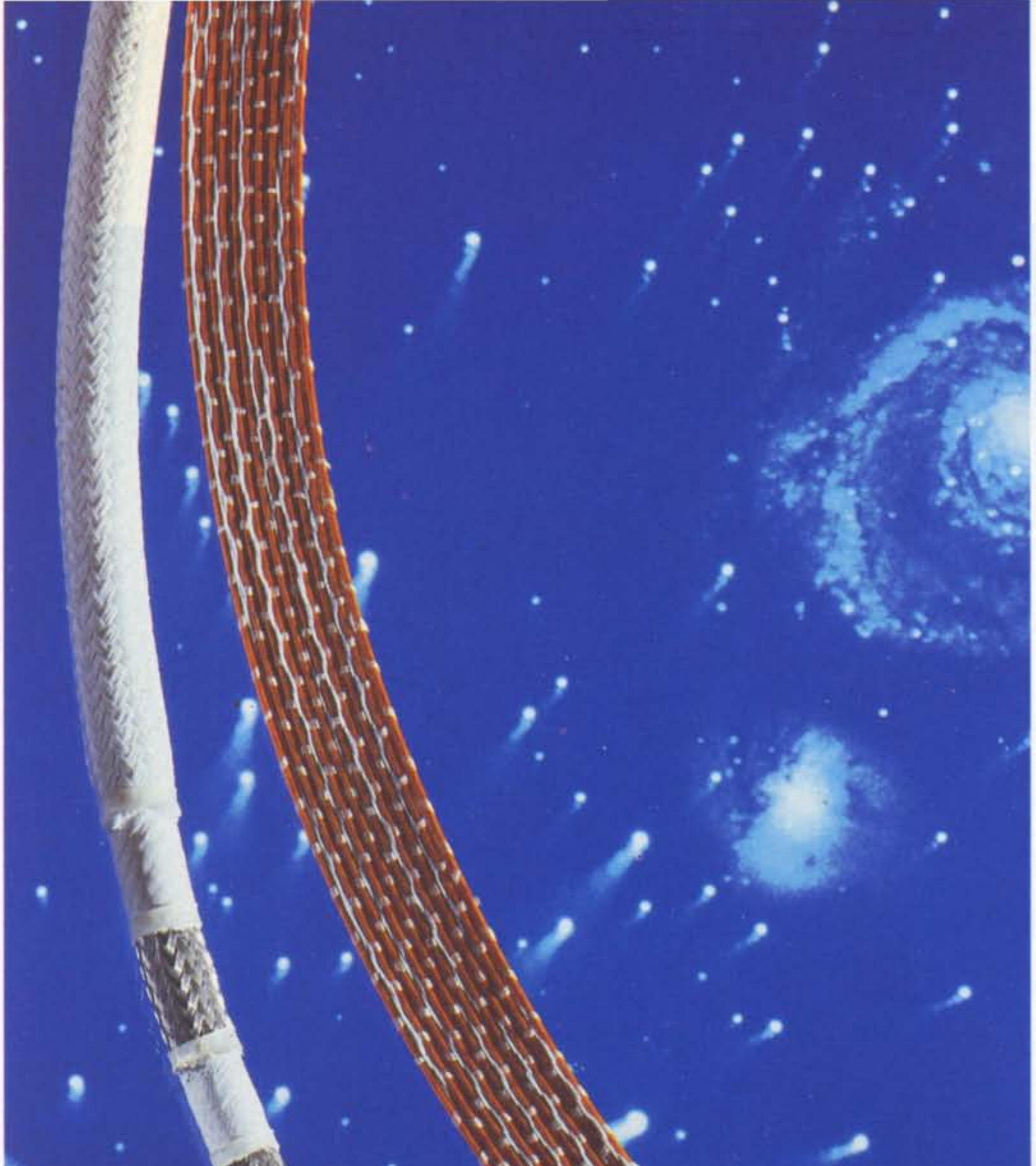
A NEW STATE-OF-THE-ART



EXTERNAL FET

FET CAN BE COOLED

NOISE: < 100e⁻RMS (Room Temp.)
< 20e⁻RMS (Cooled FET)
POWER: 19 mW typical
SLEW RATE: > 475 V/ µs
GAIN-BANDWIDTH f_T > 1.5 GHZ



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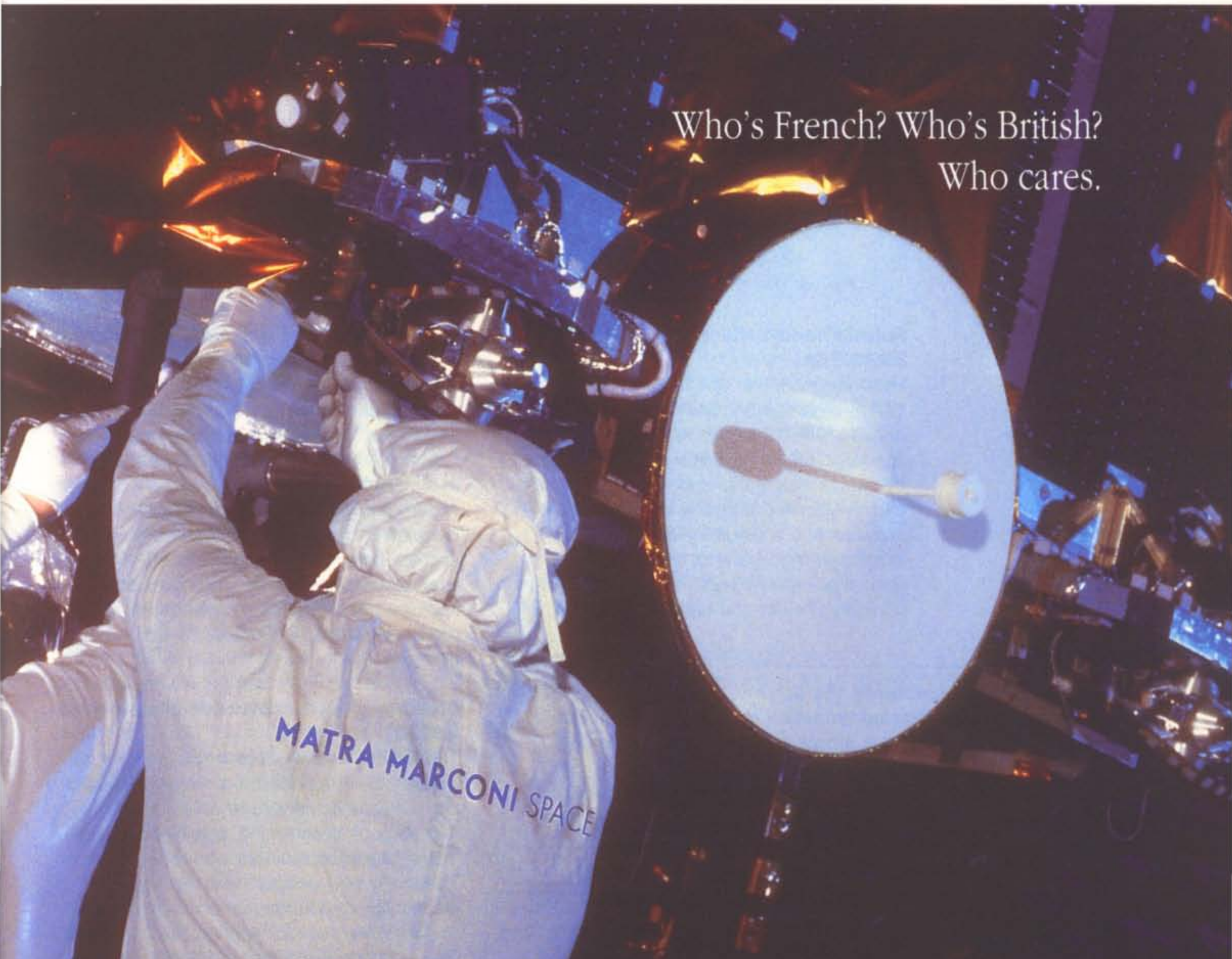


MATRA MARCONI SPACE

Space-Vehicle Aerothermodynamics

W. Berry & J. Haeuser
Propulsion and Aerothermodynamics Division, ESTEC, Noordwijk, The Netherlands

'Aerothermodynamics' embraces the science and technology of classical aerodynamics, thermodynamics and thermochemistry. This unique combination into a single technical discipline has evolved with the space age, to solve problems associated with high-speed air flow around launch vehicles during atmospheric ascent and around re-entry vehicles during Earth- and planetary-atmosphere penetration and descent, as well as those associated with internal flow through vehicle propulsion systems.

Aerothermodynamics activities in ESRO/ESA

From the inception of ESA in 1964 (via its parent organisations ESRO and ELDO) until August 1988, when the establishment of a specialist section at ESTEC for aerothermodynamics was authorised, the Agency has had very limited and dispersed technical activities and a resulting small capability in aerothermodynamics, limited to two specialised areas. The reasons for this were primarily twofold: the earlier ESRO/ESA space missions were all exoatmospheric, and there were no Earth or planetary re-entry missions; the only vehicles requiring at least a classical aerodynamic capability were the ELDO-built Europa launcher and its successor Ariane, for which technical responsibility has been delegated entirely to the Agency's Member States.

The two specific aerothermodynamic activities undertaken by ESRO/ESA during the period 1964 to 1988 were devoted to satellite aerodynamics for low-Earth-orbit missions, and rocket-engine exhaust-plume dynamics. The first of these was conducted both at ESTEC, where responsibility for satellite design was vested, and at ESOC, which was charged with trajectory analysis and satellite operation and control. This work was necessary to determine atmospheric drag, lift and moment coefficients for specific satellite configurations, to enable satellite attitude and orbit perturbations and decay characteristics to be evaluated. The plume-dynamics work was developed primarily through contracts with the DLR Institute of Fluid Mechanics in Göttingen, Germany, and at the Technical University of Hamburg-Harburg where the heating and contamination effects were studied. This work was essential to provide a design database for calculating disturbance forces and moments, and the heating and contamination of the spacecraft surfaces that are unavoidably impinged upon by the plumes of the small rocket engines used for attitude and orbit control.

Creation of an aerodynamic capability at ESTEC

The ESA Ministerial Conference in Rome in January 1986 authorised a major increase in the scope and magnitude of the Agency's future space programme, and hence in the technical capabilities that would be needed. The major new programmes involving substantial aerothermodynamics are: Ariane-5; the Hermes spaceplane; and the Space Science: Horizon 2000 Programme, which has planetary research as one of its four research cornerstones. The current planetary missions under study – the Huygens probe, the Rosetta mission, and a Mars science mission – all require an advanced aerothermodynamics capability for success.

Also in 1986, world attention and interest was revived in the potential use of air-breathing propulsion for reusable launchers, with the announcement by the United Kingdom of their Hotol (Horizontal Take-Off and Landing) reusable, winged, combined-propulsion, single-stage-to-orbit (SSTO) launcher. The announcement of Hotol triggered a stepping-up of activities in similar SSTO and two-stage-to-orbit (TSTO) concept studies in the major space-faring nations: the National Aerospace Plane in the USA; the Sänger in Germany; the Star-H and the

STS-2000 concepts in France; and similar programmes in Japan.

To keep abreast of developments and to develop a basic competence in these advanced launchers, ESA has also initiated its own generic studies of winged launchers, for which major technical developments in hypersonic aerothermodynamics are a pre-requisite.

The creation of an aerothermodynamic capability within ESA therefore became essential for the coordination of the efforts of the European aerothermodynamics community, which will undertake the aerothermodynamic analyses and vehicle designs for these major new projects. A specialist Aerothermodynamics Section was established in August 1988 in the Propulsion and Aerothermodynamics Division at ESTEC in Noordwijk (NL). This new Section is supported by the ESTEC Mathematics and Software Division's Analysis and Programming Section.

Having entered the aerothermodynamics field very late and without any specialised facilities, it has been a challenging and demanding task to establish a modern aerothermodynamics capability quickly. This has necessitated: the recruitment of qualified staff; the acquisition of advanced computer hardware; the procurement and development of aerothermodynamic computer codes; the preparation and implementation of a technology R&D programme in advanced aerothermodynamics; the provision of specialist technical support in aerothermo-dynamics for the various ESA programmes; the coordination of aerothermodynamic activities and the establishment of mutual cooperation with the aerothermodynamic communities in the Agency's Member States and those of other space agencies.

The ESA/ESTEC Aerothermodynamics Section is now exactly two years old, making this a timely moment to present here: the aerothermodynamics challenges for the Agency's future space missions; the technical capabilities needed to solve the problems posed by these challenges; the R&D activities engaged in by the Agency to advance Europe's expertise in aerothermodynamics.

Aerothermodynamic challenges for future ESA missions

The Agency is faced with challenging aero-thermodynamics problems in several of its future Science, Earth-Observation and Space-Transportation Programmes.

Science-Programme challenges

The Cassini/Huygens Mission

Cassini/Huygens is a joint NASA/ESA mission to investigate Saturn and its planet-sized moon Titan, to be launched in 1995. A NASA-supplied orbiter vehicle carrying the ESA-supplied Titan probe called 'Huygens' will first enter the orbit of Saturn, from where the probe will be released to descend to Titan's surface, performing scientific investigations during the descent phase.

The aerothermodynamic challenges are:

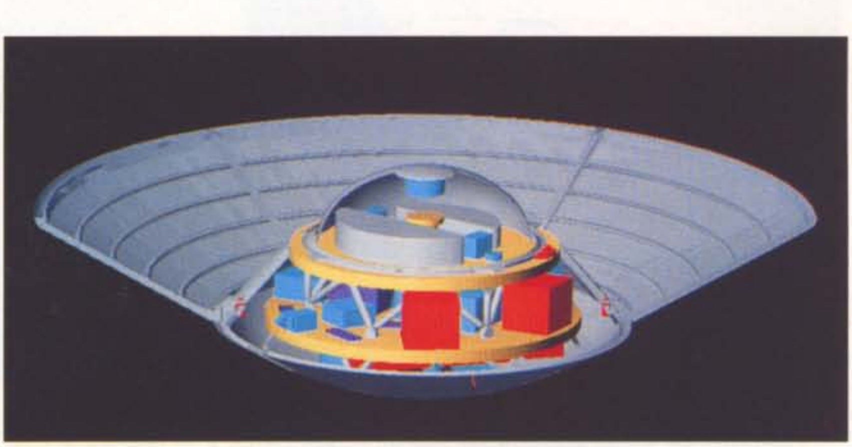
- reduction of the probe's speed from about 6 km/s as it enters Titan's atmosphere to a few m/s as it lands on the moon's surface
- maximising of the probe's descent time to maximise the time for scientific investigation
- ensuring attitude stability of the probe throughout its descent
- ensuring that the probe's scientific instruments are not overheated or contaminated during the descent.

The aerothermodynamic design solutions evolved to solve these problems, whilst still ensuring the scientific objectives of the mission, are:

- use of drag-shield aerobraking to reduce safely the probe's high entry speed
- use of sequential deployment of primary and secondary parachutes to provide a controlled descent after the jettisoning of the drag shield at the end of the aerobraking phase
- spin-stabilisation at about 10 rpm of the probe throughout its descent
- use of beryllium as a low-mass, non-contaminating thermal-protection material for the drag shield.

The probe configuration resulting from the various feasibility studies (Fig. 1) is a

Figure 1. Configuration of the Huygens Titan Probe



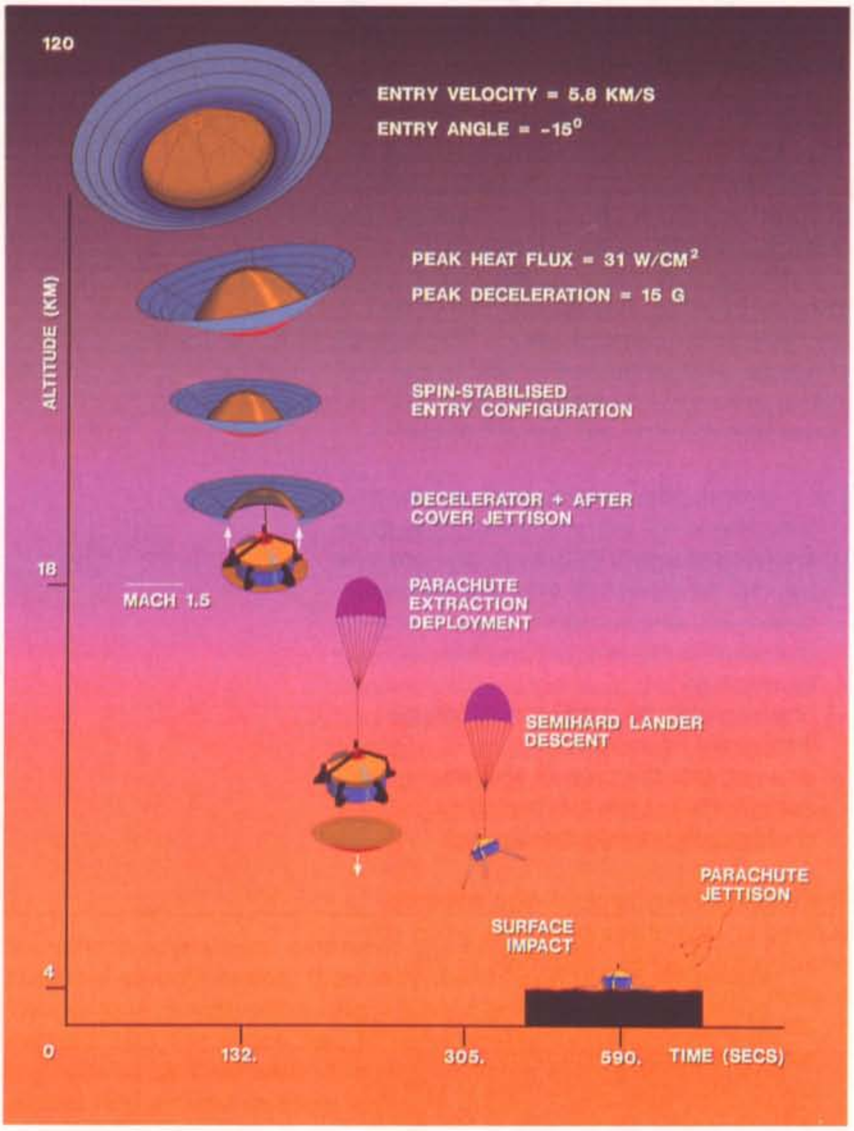


Figure 2. The Huygens Titan Probe descent scenario

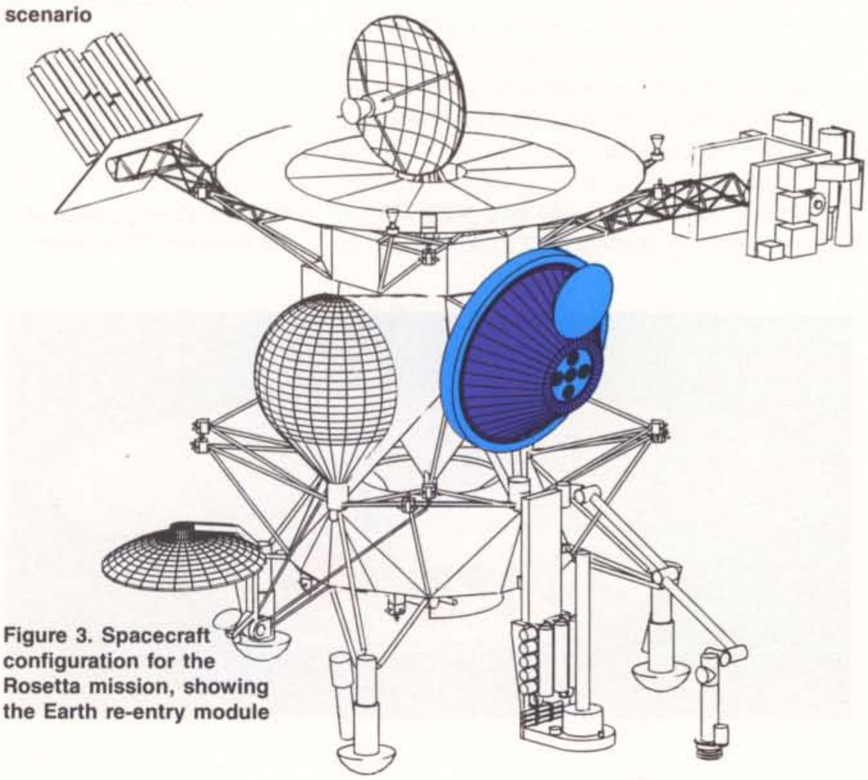


Figure 3. Spacecraft configuration for the Rosetta mission, showing the Earth re-entry module

'sphere–cone' aeroshell that provides maximum drag and acceptable stability through spin-stabilisation. The probe's descent scenario is shown in Figure 2.

Several unique features of the spinning probe's design result from the aerothermo-dynamic requirements, including the deployment of the primary parachute at a supersonic speed ratio of about Mach 1.5, and the need for a mechanism to despin the probe's parachutes.

Other major and fundamental aerothermodynamic problems are associated with the uncertain composition, mass density and temperature variations with altitude of Titan's atmosphere. Together with the unknown strength and direction of Titan's winds, these uncertainties necessitate an aerothermodynamic design with large stability and thermal-protection margins.

The Rosetta Mission

Rosetta is a joint NASA/ESA mission, currently in the feasibility-study phase, designed to collect cometary samples and to return them safely to Earth for examination. This is to be achieved by launching a spacecraft (Fig. 3) carrying a lander vehicle equipped with an Earth-return capsule, to rendezvous with a specified comet. The lander vehicle will descend to the comet's surface under its own retro-propulsion, collect and store drilled samples of the cometary soil, ascend again under its own propulsion, and return to Earth, where it will enter the Earth's atmosphere and descend to the surface. The total mission from Earth lift-off to Earth landing will take about 8 years.

The aerothermodynamic challenges involved are:

- reduction of the capsule's speed from 16 km/s at re-entry into the Earth's atmosphere to a few m/s on landing, whilst limiting the resulting kinetic heating so that the cometary samples can be preserved at their collection temperature of about 130 K, and limiting the mechanical load on the samples by limiting the vehicle deceleration to less than 100 g
- control of the re-entry trajectory to land the capsule in a specified target zone.

Two types of re-entry capsule have been studied to meet these requirements: a guided capsule with some lift to improve the precision of flight along a prescribed trajectory, to widen the re-entry flight corridor, and to minimise the heat flux to the capsule;

and a simpler, less costly unguided, spin-stabilised capsule, requiring a steeper ballistic descent to limit landing zone dispersion, at the expense of a higher heat flux. Both concepts involve deployment of parachutes at lower altitude to reduce the landing speed (Fig. 4).

The Mars Mission
The Agency is currently engaged in early feasibility studies on a mission to Mars, to take place in about 1998, which could result in a collaborative programme with NASA and other space agencies. The current missions under study are: an orbiter mission for Mars observation science; a lander mission to deploy a Rover vehicle for Mars surface-science investigations; and a lander mission to simultaneously deploy several surface probes and/or surface penetrators (Figs. 5 & 6).

The aerothermodynamic challenges for the lander missions are:
- reduction by aerobraking of the entry velocity into the Martian atmosphere, which can be as high as 6 km/s for direct entry from a hyperbolic trajectory, but somewhat lower if entry is made from a circular or elliptical Mars orbit after a retro-propulsion manoeuvre
- selection of a guided lifting descent trajectory or an unguided ballistic spin-stabilised trajectory: the guided vehicle would be more complex and costly, but would allow more accurate steering to the target zone; the unguided vehicle would be simpler, at the expense of lower targetting accuracy and higher peak heat fluxes.

These Mars studies are still at an early stage and much more work is needed before definite descent-vehicle design choices can be made. As for the Titan lander, uncertainties in the composition, mass density and temperature variations with altitude of the Martian atmosphere, as well as the assessment of the flow parameters in the shock layer and gas/surface interactions, pose fundamental problems for the aero-ermodynamic design of the lander vehicles.

Earth-Observation challenges

The Aristoteles Mission
Aristoteles will be the first satellite mission to undertake global measurement of the Earth's gravitational field from space, and may also include measurements of its magnetic field and precise measurement of the position of specific objects on Earth. The programme is currently in an advanced definition phase.

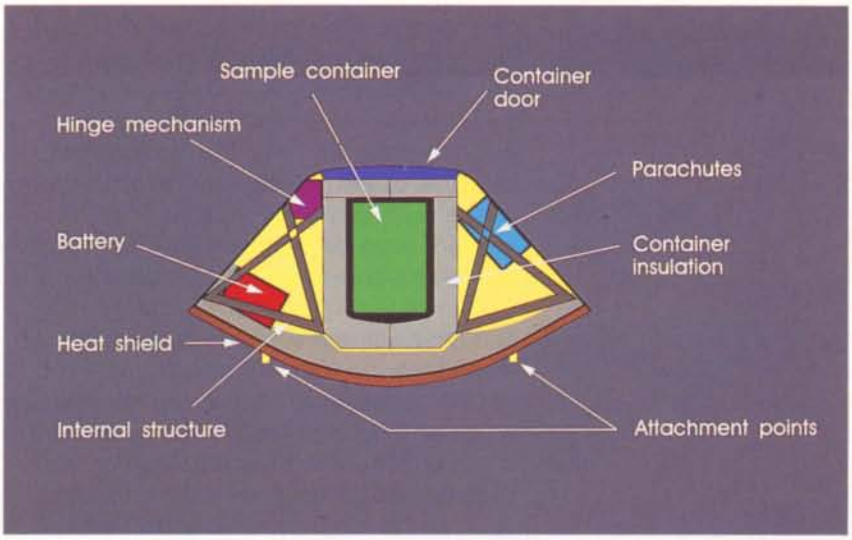


Figure 4. The aerocapsule configuration for the Rosetta mission

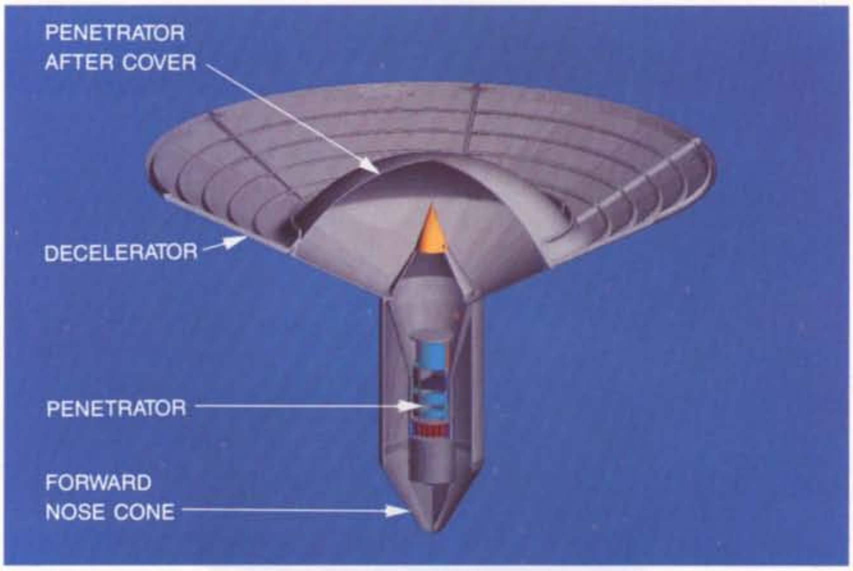


Figure 5. Concept for the penetrator entry-module for the Mars mission

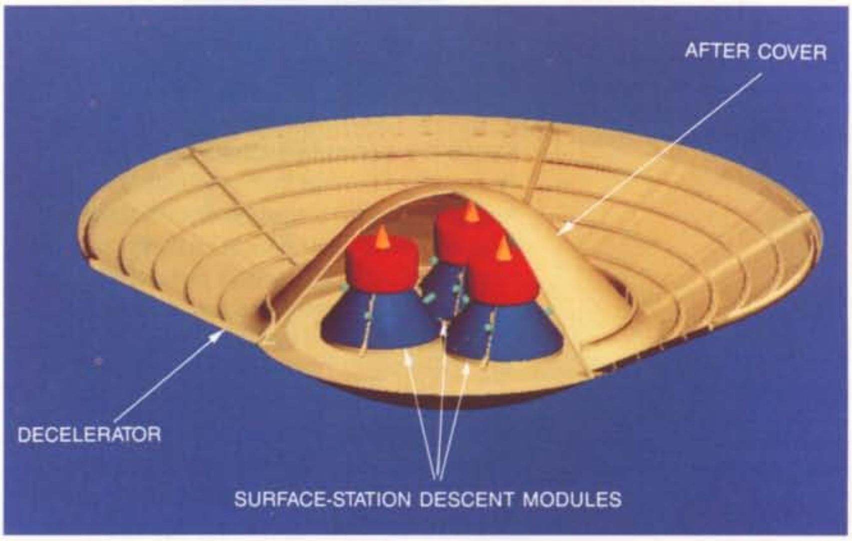


Figure 6. Concept for a surface-station ballistic entry vehicle for the Mars mission

The selected orbit to meet these objectives is a polar circular orbit of 200 km nominal altitude, and the satellite needs to be three-axis-stabilised for the required precision pointing of the scientific instruments. The satellite's centre of mass must be accurately known and controlled throughout the mission, because this impacts fundamentally on the gravity-measurement accuracies.

The aerothermodynamic challenges are:

- At the low orbital altitude of 200 km, residual air pressure at the orbital speed of about 8000 m/s is sufficient to cause satellite orbit and attitude perturbations due to aerodynamic drag, lift and turning moments about all three axes.

  The aerodynamic drag, lift and moment calculations as functions of the spacecraft's orientation to the orbital velocity vector show a need to provide four small, adjustable aerodynamic flaps at the front end of the spacecraft for attitude control (Fig. 7).

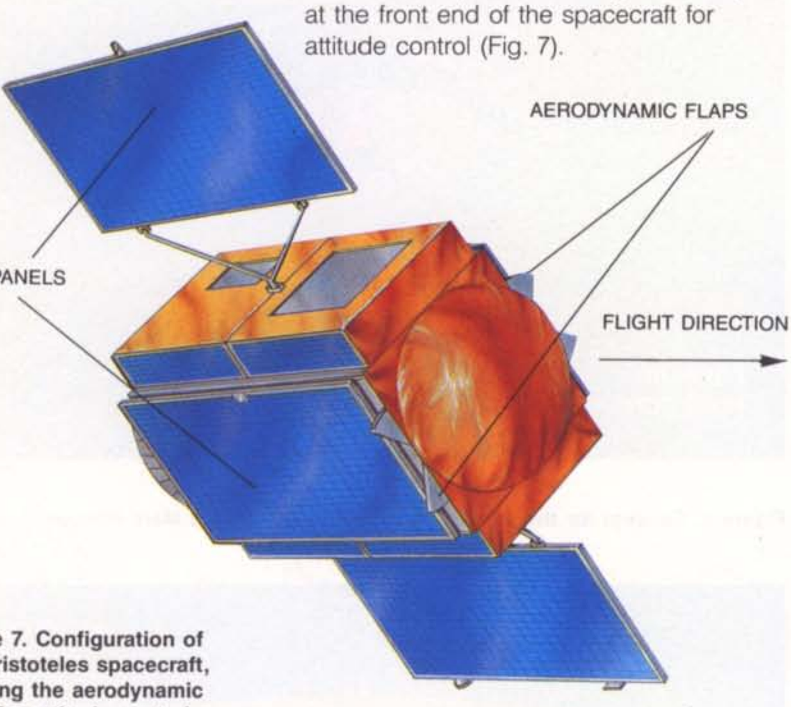


Figure 7. Configuration of the Aristoteles spacecraft, showing the aerodynamic flaps for attitude control

Space-Transportation Challenges

Ariane-5

Ariane-5, Europe's new heavy-lift launcher that will come into service in 1995, will be capable of launching large payloads or the Hermes space plane into low Earth orbit (Fig. 8).

The aerothermodynamic challenges are:

- design of the vehicle for minimum drag, including the base drag which is strongly influenced by the exhaust-plume interactions of the two solid-propellant motors and the central liquid-propellant engine
- configuration design for minimum lift to minimise bending loads on the vehicle, especially for the Hermes launch
- aerodynamic design of the fixed-geometry exhaust nozzle of the liquid-propellant engine, to maximise its specific impulse over the altitude range of the launch trajectory, and to ensure that nozzle flow separation does not occur during the early phase of the flight in the lower atmosphere.

Hermes

The Hermes reusable spaceplane (Fig. 9) is currently the most challenging aerospace project in Europe in terms of aerothermo-dynamic design. This Ariane-5 launched vehicle re-enters the Earth's atmosphere after a retro-propulsive manoeuvre from its propulsion system. Its flight regime ranges from hypersonic flight velocities of about Mach 25 as it re-enters the Earth's atmosphere, progressively reducing its speed by aerodynamic drag on an aerodynamically controlled, gliding trajectory, through supersonic, transonic and finally very low subsonic speeds as it descends to land.

European experience and capabilities for winged vehicles like Hermes are currently

Figure 8. Artist's impression of Europe's Ariane-5 launcher in its unmanned (left) and man-rated (right) configurations

limited to about Mach 4, being based on the development of the Concorde supersonic airliner (Mach 2.2) in the late 1970s and several subsequent advanced military-fighter aircraft. Lifting hypersonic flight is therefore a demanding new technology for Europe and, although hypersonic aerodynamic research had been actively pursued in many European universities and research institutes in the 1950s and early 1960s, these activities had virtually ceased by 1970.

To develop the existing capabilities fully and to meet the challenges specific to the Hermes vehicle in particular, a major new coordinated hypersonic aerodynamic research programme and the creation of new aerodynamic facilities have been initiated in Europe.

The aerothermodynamic challenges are:

- The vehicle's aerodynamic design must ensure efficient, stable flight over the speed range from Mach 25 at Earth re-entry, to Mach 0.4 at landing touch-down. The vehicle must also be able to fly through the full range of flow regimes (free molecular at re-entry, through transition flow, and finally a continuum flow regime where the maximum heat flux occurs at about 70 km altitude).
- The aerodynamic design must satisfy the minimum cross-range requirements of 1850 km for landing at Istres, France, on a 3 km-long runway.
- The vehicle must be aerodynamically stable at the high angles of attack and bank angles required to control the frictional heating during re-entry as the vehicle is decelerated by aerodynamic drag and lift.
- The vehicle's aerodynamic design must avoid, or at least limit, the degree of shock-wave interaction, which is a major cause of vehicle heating. A novel feature of Hermes' design is that the craft is always inside the bow shock cone emanating from its nose during re-entry (in contrast to the US Space Shuttle, where the bow shock from the nose interacts with the strake-wing).
- The aerothermodynamic design for the hypersonic flight phase must be based on high-temperature gas dynamics because of the chemically reacting nature of the very hot air flow around the vehicle due to kinetic heating. Atomic oxygen is a highly reactive gas and its abundance under hypersonic flow conditions can result in chemical reactions with the vehicle's thermal-protection system, causing rapid deterioration of the surface properties.
- The aerodynamic design of the vehicle for the hypersonic flight phase has to be based largely on computational methods, because wind tunnels cannot adequately simultaneously reproduce the governing flow parameters (enthalpy, Reynolds' number, Mach number, and gas composition) above Mach 8.
- The vehicle's aerodynamic design must be progressively developed and refined using the evolving database and computational tools of a coordinated European hypersonic aerodynamic research programme, involving about 70 different research activities in progress throughout the Agency's Member States.

Figure 9. Artist's impression of Europe's Hermes spaceplane docked with the Columbus Free-Flying Laboratory for servicing purposes

- The aerothermodynamic margins must be sufficient to guarantee a safe first flight for Hermes. The spaceplane's aero-thermodynamic design will only be fully validated after that first, unmanned, automatically controlled flight.
- Assessment of canopy heat load during the ascent phase in the transitional regime.
- Assessment of the aerodynamic heating due to reattachment of separated flow on the body flap and elevons.
- Assessment of the aerodynamic heating associated with flow through gaps in the rudder/elevon area.
- Estimation of boundary-layer transition on the windward side and associated unsymmetric moments;
- Design of new hypersonic facilities such as those in Toulouse (F), Göttingen (D) and Naples (I) and, very importantly their associated measurement techniques.
- Assessment of wing buffeting at transonic speed.

Reusable winged launchers
Reusable, winged, combined-cycle-propelled (air-breathing plus rocket propulsion) launchers have a high potential to reduce space-transportation costs because of their complete reusability. Horizontal take-off and landing also offers operational versatility because the vehicles could be deployed from several launch sites using airline-type operations, allowing efficient transportation with short turn-around times to a multiplicity of Earth orbits. In particular, such vehicles would be ideal as personnel transporters, for Space-Station crew exchange, and for rescue missions. Their realisation will depend on man's ingenuity to develop the advanced technologies needed, including advanced combined-cycle propulsion systems, advanced high-specific-strength materials, and last but not least advanced aerothermodynamics. Theoretical studies in Germany on Sänger (Fig. 10) and in the UK on Hotol (Fig. 11), and ESA's studies of both SSTO and TSTO vehicles, provide confidence that such vehicles are indeed technically feasible.

The aerothermodynamic challenges for such reusable winged launchers are:
- The design analysis must treat the airframe and propulsion systems as a single entity. The air-breathing engines will depend on efficient compression of the air flow into the air intakes by the under-forebody of the airframe; the engines will discharge their propulsive exhaust jets onto the airframe under-rearbody, which must be shaped to perform as an expansion nozzle.
- The aerodynamic design must result in an efficient and stable vehicle (one or two stages) to fly the ascent trajectory over the Mach number range of about 0.5 for take-off, up to about Mach 25 at 100 km altitude for injection into low Earth orbit. It must also allow efficient and stable flight over the same Mach number range for the descent trajectory as for Hermes. In this case, however, the aerothermodynamic challenges are compounded by the fact that the same vehicle also has to 'fly' efficiently along the ascent trajectory.
- To match the air-breathing engine's performance to flight altitude and Mach number, it will be necessary to have variable air intakes and exhaust nozzles. Internal flow through propulsion systems will be an important factor. The air intakes will have to convert the kinetic energy of the incoming air, already precompressed by the airframe forebody, into pressure energy to match the engine requirements. The engine nozzle throat area will also have to be continuously and automatically matched to the flight altitude and Mach number.

Figure 10. The Sänger two-stage-to-orbit, re-usable winged launcher (courtesy of MBB)

Figure 11. The Hotol single-stage-to-orbit, re-usable winged launcher (courtesy of BAe)

Technical capabilities needed for modern aerothermodynamics

Design tools

Design tools may be classified into: engineering tools, consisting of the simpler analytical models of classical aerodynamics, which are ideal for early and rapid assessment and feasibility studies to derive aerodynamic force and moment coefficients for the sizing of vehicles and deriving their configurations: and computational-fluid-dynamics tools, which are complex numerical computer codes for solving two- and three-dimensional flow problems, modelling either the Euler equation for flow systems in which fluid viscosity effects can be neglected, or the more difficult Navier-Stokes equations for flow systems in which viscous effects are significant.

The rapid development in recent years of high-speed, large-memory digital computers, has been the major impetus in the development of numerical simulation techniques. Computational-fluid-dynamics methods are now essential for the refined aerodynamic calculations that are needed for complex vehicles like space planes and reusable winged launchers.

For the numerical simulation (electronic wind tunnel), three inter-related and essential technical capabilities are required: grid generation, flow-field solution, and graphical presentation and visualisation of the computed results. Grid generation is a highly specialised activity and the grid system selected depends primarily on the complexity of the vehicle's geometry and the accuracy required of the solution. It is not uncommon for six to nine months to be spent generating a grid for a complex aircraft, and the numerical solution can take about 20–30 h on a supercomputer. Major efforts are now underway to reduce human interaction in grid generation.

Specialised graphics have been developed for the presentation of results on powerful purpose-built work stations, and the enormity of the computational task for large and complex vehicle geometries, which can involve a few million grid points, has triggered activity in the development of parallel processing to achieve a major reduction in computational costs (Figs. 12–15).

Engineering facilities

The engineering facilities required for aerothermodynamics include wind tunnels and facilities for in-flight testing. Associated

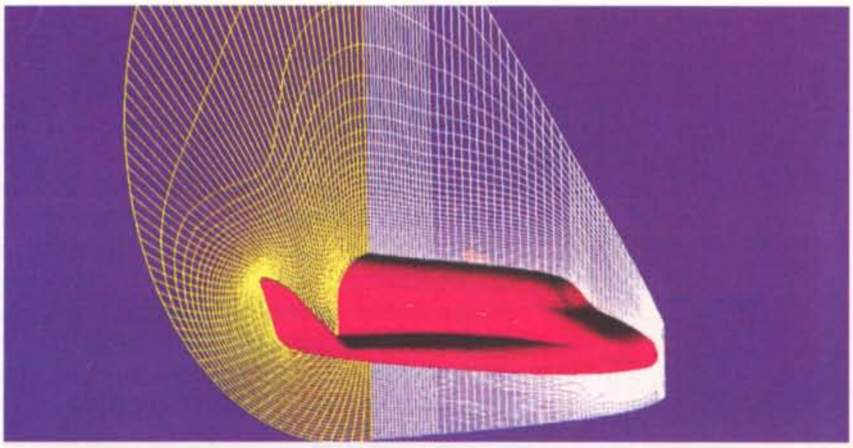


Figure 12. A typical structured volume grid for the Hermes spaceplane

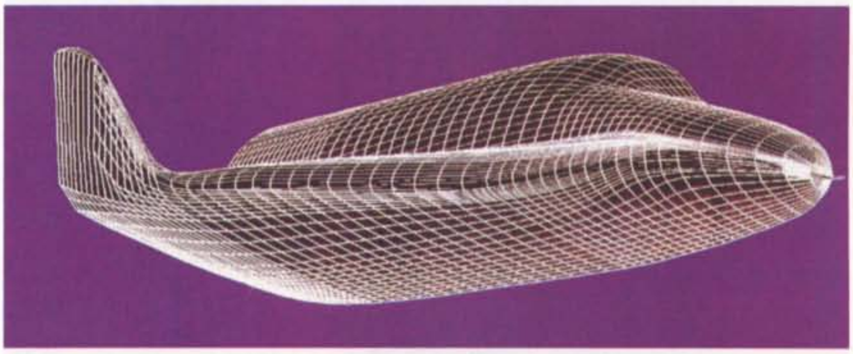


Figure 13. A typical surface grid for the Hermes spaceplane

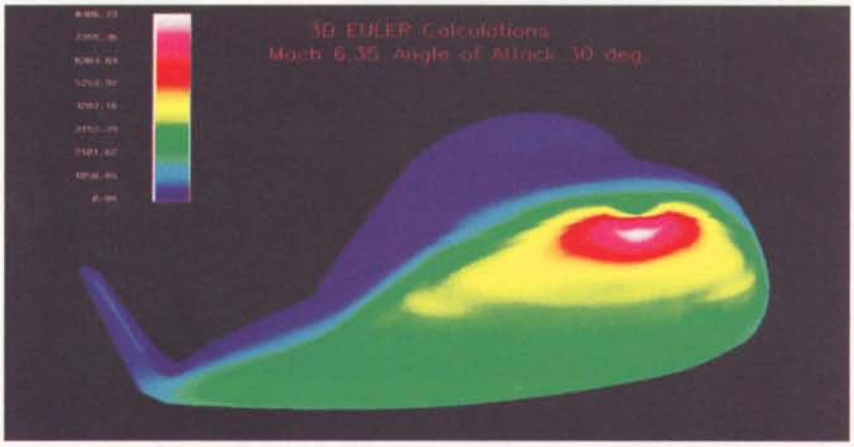


Figure 14. Computed surface-pressure distribution for the Hermes vehicle. Red represents high-, and blue low-pressure areas

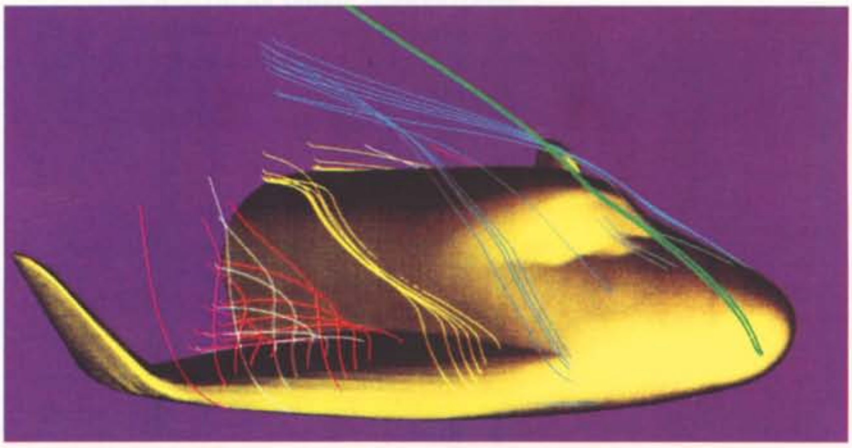


Figure 15. An example of particle-tracing (flow streamlines) around the Hermes vehicle

with the wind tunnels are the instrumentation systems needed for the accurate measurement of aerodynamic forces and torques, pressures and temperatures, non-intrusive methods for flow visualisation (Fig. 16), air-flow velocity measurement, species concentration, and vibrational temperature measurements.

Because wind tunnels must be specifically designed to simulate flow conditions over a specified Mach and Reynolds' number range, several wind tunnels are needed to cover the complete flight range up to supersonic Mach numbers. For hypersonic flow (defined here as greater than Mach 5), short-duration testing for up to a few milliseconds is possible in so-called 'shock tubes'. For the exposure testing of thermal-protection materials under representative temperature and duration conditions, so-called 'arc-heated' tunnels are used.

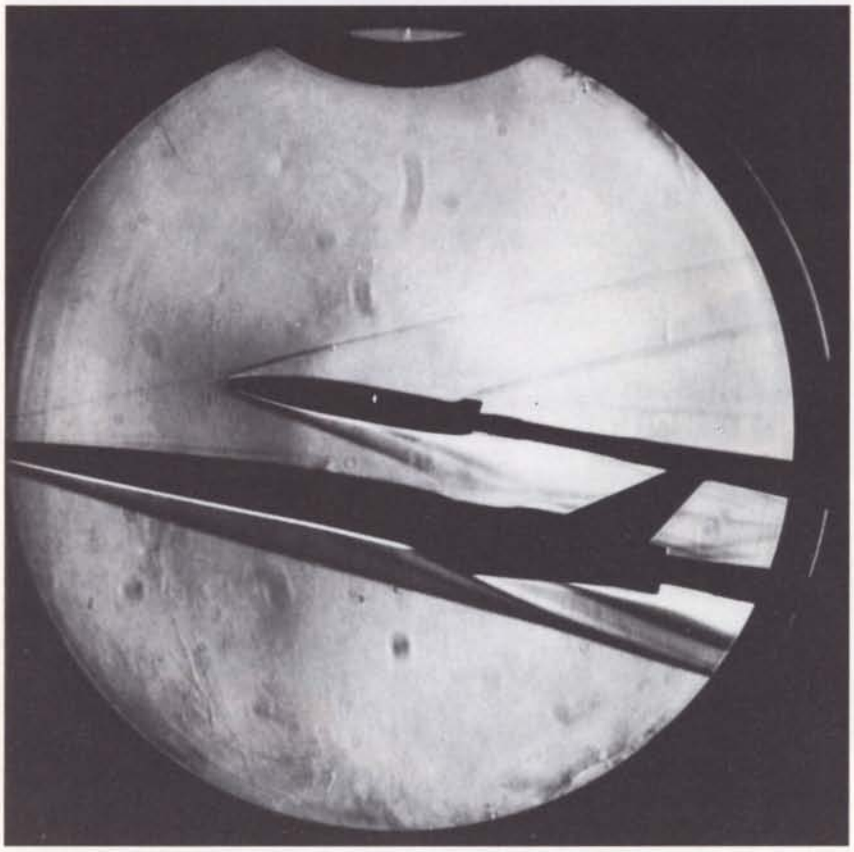


Figure 16. Wind-tunnel testing of a model of Sänger (1:160 scale) (courtesy of DLR and MBB)

To meet the needs of the Hermes Programme, four major new wind-tunnel facilities are nearing completion in Europe: the F4 Wind Tunnel at ONERA in Toulouse (F); the High-Enthalpy Tunnel at DLR in Göttingen (D); the Simoun arc-heated tunnel (existing facility being updated) at Aerospatiale in Bordeaux (F); and the Scirocco arc-heated tunnel at CIRA in Naples (I).

Facilities for flight testing under hypersonic flow conditions are urgently needed. The Agency currently has no such facilities of its own but is closely following studies and developments taking place within the national space programmes of its Member States, in Germany, in The Netherlands and in Italy (see Table 1).

Table 1. Hypersonic flight-testing programmes currently in progress in Europe.

COBRA	German national programme currently in the study phase. Cobra is an instrumented aerodynamic body launched into suborbital trajectories (COBRA-A), with re-entry from a low Earth circular orbit (COBRA-B), and variable low-perigee altitudes in a geostationary transfer orbit (COBRA-C). The three versions of COBRA will allow the investigation of aerothermodynamic phenomena over flight-velocity Mach numbers from 5 to 30, covering the complete flight envelope (free molecular, transition and continuum flow regimes).
FALKE	German national programme which entered its operational phase in 1989. An instrumented model of the vehicle is carried to altitudes of about 40 km by balloon and then released, achieving velocities up to Mach 2 in free-fall through the atmosphere.
LARVE	Dutch national programme in the feasibility-study phase. It comprises an instrumented aerodynamic body housed in the interstage adaptor (stages 2/3) of the Ariane-4 launcher. LARVE is automatically released after 2nd/3rd-stage separation and re-enters the atmosphere on a ballistic trajectory.
TSS-2	Tethered Satellite System 2 is a joint project by the Italian Space Agency (ASI) and NASA for aerothermodynamic research in the upper atmosphere using an instrumented, tethered satellite deployed towards Earth to an altitude of about 130 km from the Shuttle Orbiter. It allows aerothermodynamic research in the free molecular regime.

ESA's R&D activities in aerothermodynamics

One of the Agency's primary activities is to prepare and implement a Technology Research Programme (TRP) designed to prepare the technology needed for Europe's space programme. The current TRP programme is still very modest, reflecting the fact that ESTEC's Aerothermodynamic Section has now been in existence for just two years.

Activities already in progress or planned within the TRP framework are:

- *Development of Navier-Stokes Algorithms*, involving the development of a three-dimensional, full Navier-Stokes computer code for compressible flows. Its availability will be a significant addition to the Agency's capabilities in computational fluid dynamics.

- *Work on Aerothermochemistry Effects in Hypersonic Flows*, to investigate experimentally the chemical reactions and reaction rates behind shock waves in hypersonic air flow. The results are expected to provide the database needed to allow the modelling of chemically reacting flows under hypersonic flow conditions.

- *Work on Parallel Processing for Aerothermodynamics*, to investigate the potential, cost and time savings of executing aerodynamic codes on massively-parallel computers.

- *Transition Criteria in Hypersonic Flows*, to investigate the difficult problem of determining the flow conditions that trigger transition from laminar to turbulent boundary layers in hypersonic flow. This has a fundamental influence on aerodynamic forces and heat-transfer characteristics.

- *Work on Measurement Techniques in Hypersonic Flows*, to develop and validate experimentally instrumentation techniques for determining the physical and chemical state of air flows under hypersonic flow conditions in free-flight conditions. The data-collection and data-compression systems that will be needed onboard re-entry vehicles will also be studied.

Conclusion

Aerothermodynamics is an important new technology that is essential to the success of many of the Agency's future programmes. Intensive international efforts are underway on aerothermodynamic research in general and on devising computer codes for high-speed flow simulation in particular, as these powerful tools will enable major advances to be made in a broad range of future space projects. In setting up its own specialist section for aerothermodynamics, the Agency has recognised the importance of this technology for tomorrow's space applications and of Europe maintaining a leading role.

Définition des formes aérodynamiques d'Hermès

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Les défis technologiques majeurs du programme Hermès portent principalement sur la mise au point des protections thermiques, sur le développement des piles à combustible, et sur la conception des formes aérodynamiques du véhicule. Le présent article explique les méthodes et moyens mis en oeuvre pour définir des formes satisfaisant les objectifs du vol atmosphérique.

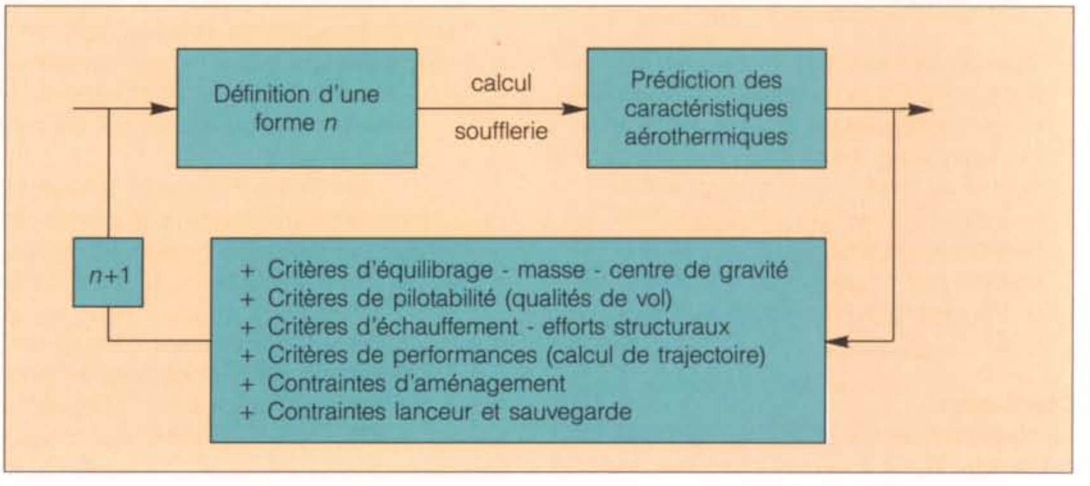
Spécifications ayant un impact sur les formes

Les spécifications du véhicule Hermès obligent les industriels à sortir du cadre des méthodes et solutions traditionnelles en aéronautique. En effet:

- Hermès vole à des vitesses comprises entre 7,5 km/s et 100 m/s et à des altitudes variables allant jusqu'à 120 km. Les caractéristiques aérodynamiques de l'avion spatial dépendent fortement des conditions du vol, et malgré ces variations, on doit pouvoir le stabiliser et le piloter sur toute sa trajectoire. La forme sera donc le résultat d'un délicat compromis entre les différents régimes de vol.
- Hermès subit l'échauffement cinétique lors de la rentrée; les formes doivent donc être étudiées pour gommer les points chauds et mettre en accord la carte des températures avec les performances des protections thermiques.
- Certaines performances minimales sont exigées; en particulier l'avion doit pouvoir rejoindre depuis son orbite nominale une piste d'atterrissage située en Europe; pour une plus grande souplesse d'utilisation, la vitesse d'approche doit être assez faible pour permettre un atterrissage dans la longueur imposée par une piste ordinaire.
- Hermès est un planeur; les conditions initiales de rentrée étant fixées après désorbitation, Hermès doit rejoindre son site d'atterrissage en dépit des perturbations atmosphériques et sans recours à un moyen de propulsion. Son énergie est gérée par le choix de la trajectoire, puis en phase finale grâce aux aérofreins. A tout moment les deux modes de pilotage, manuel et entièrement automatique, sont disponibles. Le pilote dispose d'une vision frontale extérieure.
- Hermès est placé en orbite par Ariane-5; le composite doit donc rester contrôlable pendant la phase atmosphérique, et l'éventualité d'une panne du lanceur conduit à prendre en compte dans le domaine de vol de l'avion des trajectoires de sauvegarde au lancement.

Boucle de conception de l'avion

La définition des formes et des aménagements suit un processus itératif qui est schématisé ci-dessous.



Les critères mentionnés ci-dessus ne sont autre qu'une expression chiffrée des spécifications exposées précédemment. Leur examen a lieu au fur et à mesure de la disponibilité des résultats; des variantes de la forme principale peuvent être générées pour examiner l'effet d'une modification des formes sur ces critères. La synthèse des résultats obtenus sur la forme principale et des effets dûs aux variantes permet d'imaginer une nouvelle forme de référence à l'indice $n+1$. La durée d'un cycle complet est de l'ordre de 18 mois.

Prédiction des caractéristiques aérothermiques

Les moyens et méthodes restent relativement classiques dans le domaine où nous pouvons bénéficier de l'expérience aéronautique civile et militaire (jusqu'à $M=4$). Par contre dans le domaine hypersonique ($M=10$ à 25) la prédiction est très délicate car:

- aucun moyen d'essai au sol n'est capable de simuler complètement le vol au-delà de $M=10$;
- des moyens de calcul existent qui couvrent ce domaine mais ils font appel à des approximations et à des modélisations physiques dont la validité ne peut être vérifiée par une confrontation à l'expérience; de plus, les maillages utilisés doivent rester assez grossiers car le temps de calcul augmente très vite au-delà des limites du raisonnable pour les modélisations les plus fines;
- l'industrie ne peut s'appuyer sur son propre savoir-faire; nous ne possédons pas d'expérience pour la conception d'un avion hypersonique, et les informations publiées aux Etats-Unis et en Union soviétique ne permettent pas de reconstituer ce savoir-faire.

La prédiction des coefficients aérodynamique et thermiques d'Hermès est donc obtenue de la façon suivante:

- Pour les *vitesses conventionnelles*, les coefficients sont générés par calcul puis corrigés par les résultats d'essais en soufflerie lorsque ceux-ci sont disponibles.
- Pour les *vitesses hypersoniques*, les prédictions de coefficients de vol reposent entièrement sur le calcul (Fig. 1). Des essais sont effectués dans des conditions aussi voisines que possible du vol, qui permettent de vérifier partiellement le bon fonctionnement des codes.

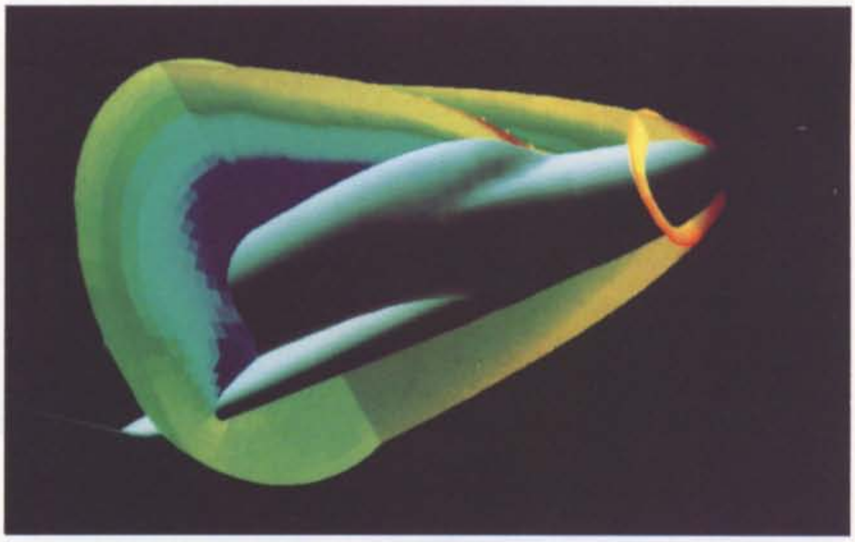


Figure 1. Calcul Euler tridimensionnel

L'implantation des souffleries actuellement utilisées dans le cadre du programme Hermès est présentée en Table 1. La remise en état des moyens européens d'essais en soufflerie a été entreprise, et des essais comparatifs avec les moyens russes ou américains sont planifiés pour calibrer nos souffleries. Quelques visualisations en soufflerie sont présentées en Figures 2 et 3.

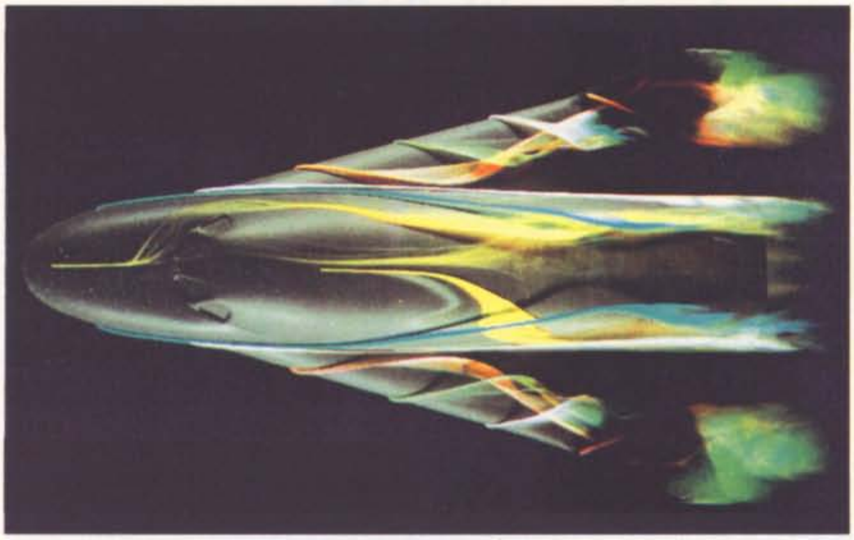
L'importance accordée aux codes de calcul malgré la difficulté que nous avons à les valider nous a conduit à prendre un certain nombre de précautions:

- Un plan d'amélioration des moyens de calcul industriels a été établi, qui doit aboutir, avant que les formes soient figées, à la prise en compte de tous les phénomènes physiques importants.

Tableau 1. Sociétés et organisations participant aux essais aérodynamiques et en soufflerie d'Hermès

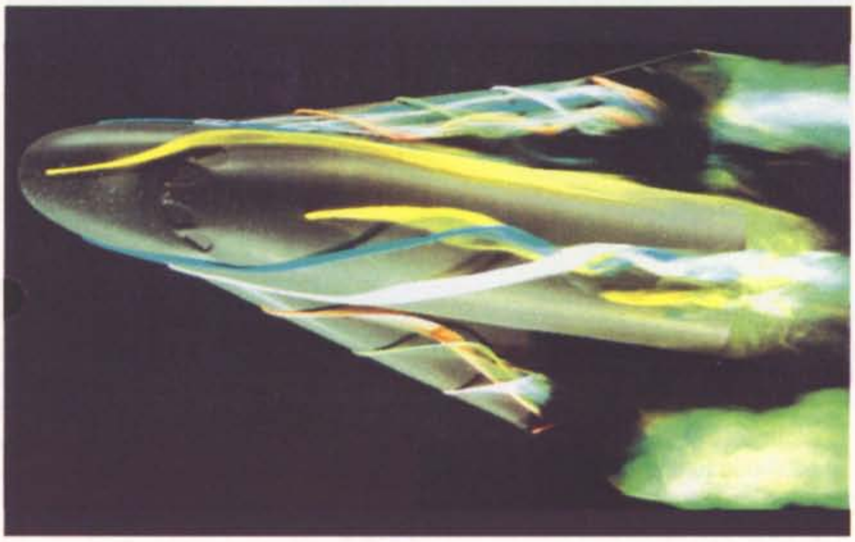
AMD-BA, Velizy, France
CEAT, Toulouse, France
CNRS, Meudon, France
DFVLR, Göttingen, Allemagne
DNW, Emmeloord, Pays-Bas
Dornier, Immenstadt, Allemagne
FFA, Stockholm, Suède et Emmen, Suisse
IAT, St. Cyr, France
LRBA, Vernon, France
NLR, Amsterdam, Pays-Bas
MBB, Bremen, Allemagne
ONERA, Chalais-Meudon, Fauga et Modane, France
RWTH, Aix-la-Chapelle, Allemagne
VKI, Bruxelles, Belgique

BAe, Canberra, Australie
Calspan, Etats Unis

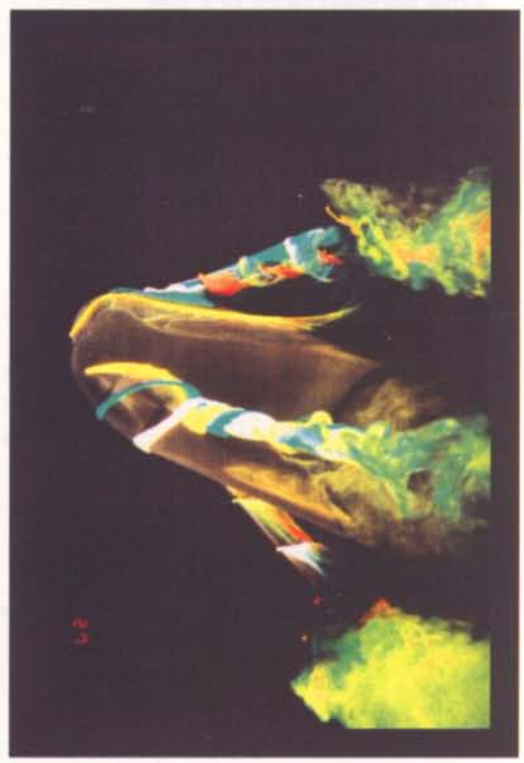


$\beta=0°$

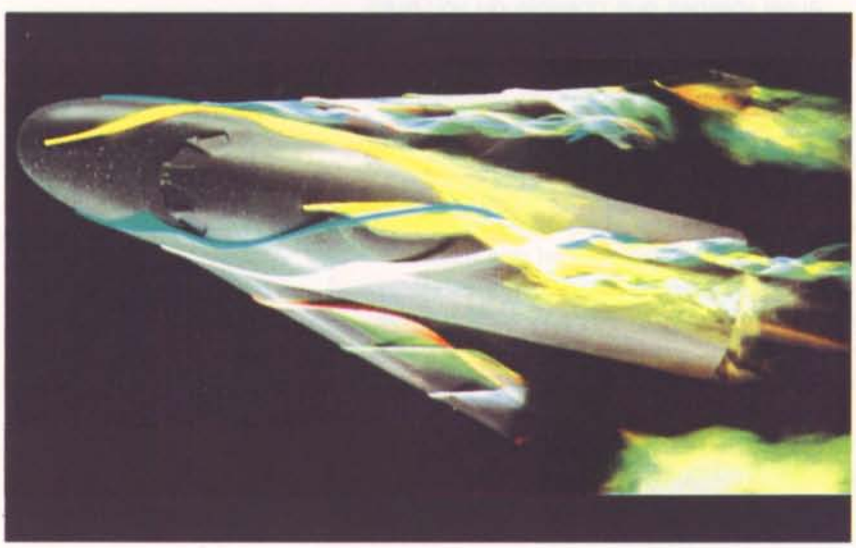
$\beta=0°$



$\beta=-10°$

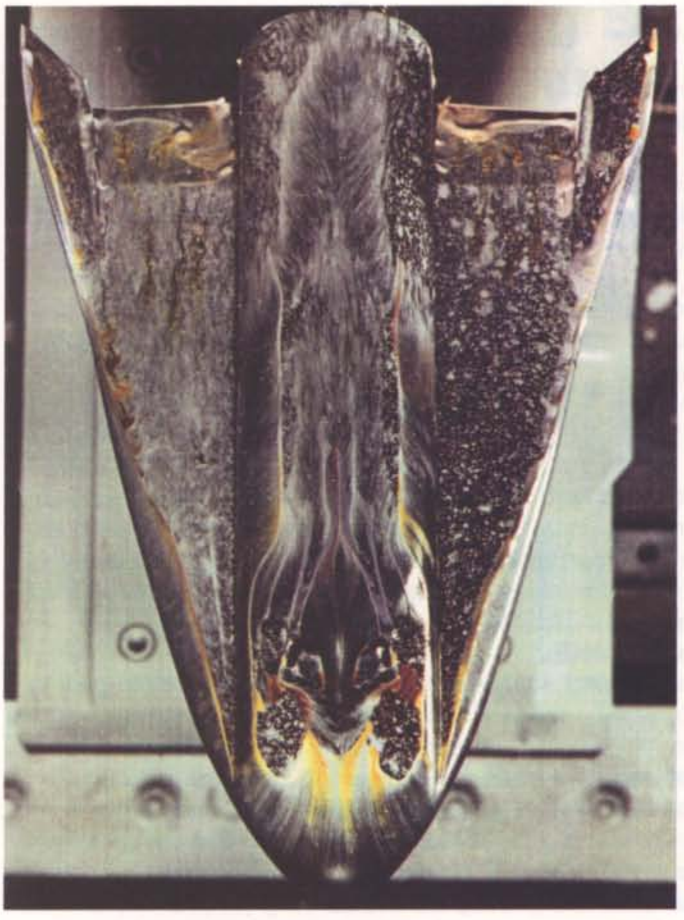


$\beta=-10°$



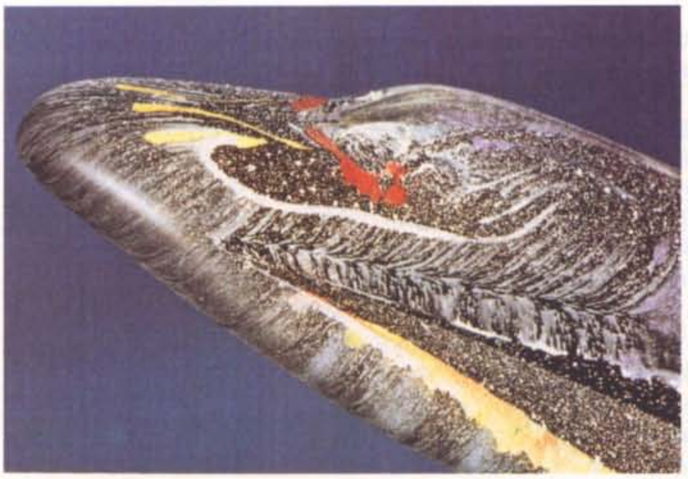
$\beta=-15°$

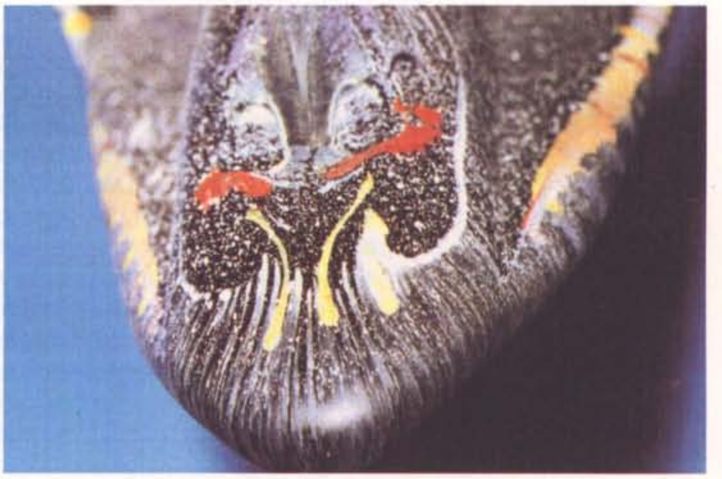
Figure 2. Influence du dérapage (β) sur l'ecoulement autour d'une maquette d'Hermès dans un tunnel hydrodynamique (à gauche, vues de l'extrados; à droite, vues perspectives arrière)



a. Visualisation pariétale extrados

b. Visualisation pariétale de profil





c. Détail du nez

Figures 3a - d. Différentes vues d'Hermès en soufflerie (Mach 6,4)

d. Détail des winglets

- Les calculs les plus importants pour la définition des formes doivent être effectués en parallèle par des industriels différents avec des méthodes de calcul différentes.
- La construction de souffleries nouvelles (F4 et HEG) permettant une meilleure simulation des conditions de vol est en cours.
- Des méthodes de mesures sophistiquées pour ces souffleries sont en cours de développement, qui permettront d'analyser finement la physique des écoulements.

Un ambitieux programme de recherche a également été lancé au niveau européen, qui porte sur:

- des travaux expérimentaux en aérodynamique fondamentale, permettant de mieux comprendre les paramètres influant sur les écoulements;
- le développement de nouveaux algorithmes performants pour les codes Euler, Navier-Stokes et Monte-Carlo, en incluant une modélisation des phénomènes physico-chimiques;
- des efforts de validation des éléments de base servant à construire les codes industriels au cours de colloques internationaux.

Incertitudes et marges

L'appréciation des incertitudes attachées à l'emploi des moyens décrits ci-dessus pose un délicat problème. Les efforts de recherche et de développement des outils de prédiction auront pour effet de resserrer la fourchette d'incertitude. Au moment de figer les formes, notre objectif est d'inclure dans la conception de l'avion des marges qui couvriront les incertitudes résiduelles.

Le concept actuel d'avion ne prend en compte que des marges forfaitaires qui ne sont pas justifiées vis-à-vis des incertitudes, car les incertitudes qui pourraient être évaluées aujourd'hui seraient très conservatrices et conduiraient à définir un avion avec des marges incompatibles avec sa faisabilité.

La couverture des incertitudes par des marges permettra de garantir le succès du premier vol inhabité. L'identification des caractéristiques aérodynamiques lors de ce vol réduira à nouveau les incertitudes, de sorte que les marges prises couvriront largement la sécurité des vols habités.

Identification finale des caractéristiques de l'avion

Les travaux aérodynamiques pour Hermès ne s'arrêteront pas le jour où les formes extérieures seront figées. Au contraire, c'est à ce moment-là que les plus gros moyens de calcul et d'essais seront engagés pour prévoir les caractéristiques définitives de l'avion. Ces efforts permettront d'affiner les lois de guidage-pilotage, fourniront des entrées aux bancs de simulation sol (GPA) ou aériens (avion d'entraînement) et permettront de définir les performances opérationnelles. Les essais en vol basse vitesse auront pour objectif de confirmer l'exactitude des prédictions aérodynamiques en basse vitesse, et de mettre au point les logiciels de guidage-pilotage en mode manuel et automatique pour la phase finale du vol.

La qualification complète de l'avion pour le vol orbital sera acquise progressivement lors du premier vol inhabité et des vols suivants. Au vu des résultats de mesures technologiques recueillies au cours des vols, le domaine de vol autorisé (masse, centrage, déport latéral, longueur de piste. . .) sera progressivement élargi jusqu'à la qualification complète dans tout le domaine opérationnel spécifié.

Conclusions

Des moyens importants sont mis en place pour faire face au défi technologique de la conception des formes d'Hermès. Ces moyens permettront de figer définitivement les formes d'Hermès et de les qualifier ensuite. Le savoir-faire ainsi constitué sera disponible pour les projets futurs de systèmes de transport spatial.

Operating Europe's Future In-Orbit Infrastructure

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The European In-Orbit Infrastructure consists of: the Columbus elements – the Attached Laboratory, the Free-Flying Laboratory and the Polar Platform; the Hermes spaceplane with its Ariane-5 launcher; and the Data-Relay System (DRS). Detailed definition of the ground facilities needed for its operation is already well underway based on a decentralised operations concept.

The elements of the In-Orbit Infrastructure

The **Columbus Attached Laboratory** is a permanently manned laboratory module which will be attached to the Space Station's Manned Base (SSMB). It will be launched and serviced by the NASA Space Transportation System and will have – after the completion of its assembly – a payload capacity equivalent to 48 single racks. Communication for the Attached Laboratory will be supported by the resources of the Space Station's communications system and by the US Tracking and Data-Relay Satellite System (TDRSS).

The **Columbus Free-Flying Laboratory** is a man-tended vehicle that will be visited by European astronauts for servicing activities every six months. Every five years, the Laboratory's Resource Module will need to be replaced, and this exchange will be carried out at the Space Station. The Free-Flying Laboratory's payload capacity is equivalent to 16 single racks.

The communications resources for the Free-Flying Laboratory are to be provided by the **European Data-Relay System (DRS)**, based on two data-relay satellites providing both S- and Ka-band services.

The **Hermes Spaceplane** will be launched by Ariane-5 into a circular orbit between 330 km and 483 km high, carrying a crew of three and its cargo to the Free-Flying Laboratory for servicing missions and also to the Space Stations. Hermes communications will be in the S-band, allowing use of the DRS satellites and additionally support from ESA's and CNES's S-band stations.

The **European Polar Platform (PPF)**, which is also a Columbus Programme element, has more in common with a conventional earth-observation satellite like ERS-1. The initially foreseen servicing of the Platform by Hermes is now no longer required, and it is planned to decouple its operation from that of the manned elements.

Central mission control – Decentralised flight operations

The operating concept for the European In-Orbit Infrastructure (IOI) is based on a three-level hierarchical management structure:

- Strategic management, to define the overall resources and control the operational activities globally, with a forward planning period of typically five years.
- Tactical management, to implement and co-ordinate the decisions of the higher level by distributing resources, supervising preparation activities, and directing mission operations, with a planning horizon of typically two years.
- Execution management, to establish the flight-operations plan for a specific mission and ultimately execute flight operations, after review and approval of the plans by the next higher level.

This structure will allow progressive definition of the operational activities in a controlled hierarchical fashion, addressing successively shorter and shorter time spans with an increasing level of detail. It will also support the decentralisation of the flight operations within clear boundaries of responsibility.

Central functions

In the IOI ground segment, the following functions (largely tactical level) will be performed centrally:

- Mission planning, supporting the strategic level in the assessment of yet to be approved missions and tactical-level mission planning for already approved missions.
- Mission preparation, involving definition of mission rules, integration of all operational activities, and validation of the ground segment for operations for a specific mission.
- Mission direction, providing supervision of IOI flight operations and of associated decentralised facilities, deciding on operating margins allocated to mission contingencies, and authorising corrective actions to unforeseen events not covered by mission rules.
- Management of communications resources, processing all network user requests for communications services.
- Central navigation support, a specialised flight-dynamics service covering navigation tactical planning support, mission advisory support, ground-station tracking support, and space-environment hazard management (e.g.space debris).

The above central functions are to be carried out by the central facilities headed by the Central Mission Control Centre (CMCC), which will be established at ESOC.

Decentralised functions

The operation of the Attached Laboratory is governed by the agreements reached between NASA and ESA on Space-Station Manned Base (SSMB) operations and will be executed as documented in the Memorandum of Understanding.

Flight-element operations will be executed by dedicated flight operations centres, which will be linked to the CMCC and with each other by a communications network making use of the Integrated Services Digital Network (ISDN) capabilities planned by the European PTTs. The following major flight operations facilities are foreseen:

- The **Manned Space Laboratories Control Centre (MSCC)**, to be established at Oberpfaffenhofen in Germany, will co-ordinate the operation of all European experiments conducted in the Attached Laboratory and elsewhere on the SSMB. It will be responsible for the Free-Flying Laboratory's system control and the co-ordination of its payload operations.
- The **Attached Laboratory Centre (APM-C)**, to be established in Italy, will provide the system-engineering support for that Laboratory's operations.
- The **Free-Flying Laboratory Centre (MTFF-C)**, to be established in Germany, will provide the system-engineering support for that Laboratory's operations.
- The **Hermes Flight-Control Centre (HFCC)**, to be established in Toulouse, France, will execute all Hermes operations.
- The **Hermes Engineering-Support Facility**, also to be established in Toulouse, will provide the necessary engineering support to Hermes operations.
- The **DRS Operations Control Centre (DRS-OCC)**, to be located in Fucino, Italy, will be responsible for DRS satellite operations control.
- The **User Support and Operations Centres (USOCs)** and **User Home Bases (UHBs)**, to be located throughout Europe, will execute payload operations.

The back-up concept for these facilities is not yet completely established, but it can be assumed that for major operational functions back-up arrangements will indeed be required.

Space-Station Manned Base operations

SSMB flight operations will be conducted from the Space-Station Control Centre (SSCC) in Houston (USA), and the Payload Operations Integration Centre (POIC) in Huntsville (USA). The SSCC will have overall responsibility for the flight operations, and particularly for system and critical operations. The POIC will be the focal point for the coordination of payload operations. Both centres will be staffed internationally, by NASA, ESA, CSA (Canada) and NASDA (Japan). Overall management will be provided by an equally international tactical operations organisation, located at Reston (Va.) in the USA, with on-site representation at the SSCC during critical phases.

The SSCC will be supported from Europe by the APM Centre, which will provide the necessary engineering expertise for the Columbus Attached Laboratory. This support will normally be provided seven days a week during normal working hours, but will be extended to provide full 24 h coverage when needed, such as during the Laboratory's assembly or during a major refit. The APM Centre will continuously monitor all Laboratory housekeeping and associated data.

The Manned Base payload operations are intended to be carried out in a distributed manner to maximise flexibility. The POIC will therefore be a coordination rather than a control centre, assisted by the MSCC, which will coordinate the operations activities of the European user community. This arrangement will allow a user in Europe to plan and conduct an experiment on the SSMB directly from his home base or from a European USOC.

Free-Flying Laboratory operations
These operations will be conducted from the Manned Space Laboratories Control Centre (MSCC) at Oberpfaffenhofen, in Germany, which will provide both the system control and the payload coordination functions. Here too, the users will have the opportunity to conduct payload operations from their own environments. An MTFF Centre, also in Germany, will furnish the necessary engineering expertise.

Overall supervision of flight operations will be provided by the tactical organisation at the CMCC.

The major difference between the Free-Flyer's operations and those of the Manned Base stems from the fact that the former will be unmanned, except for about six days every six months when servicing takes place. Consequently, the Free-Flyer will be operated via a combination of onboard automation and direct control by the user from the ground – so-called 'tele-operation'.

Hermes operations
The Hermes Control Centre in Kourou (French Guiana) will supervise the countdown, launch and injection into orbit. Thereafter, the Hermes Flight Control Centre (HFCC) in Toulouse, France, will be responsible for flight operations. The HFCC will provide flight direction, report to mission direction at the CMCC, and coordinate the dedicated engineering and ground-segment support for spaceplane operations.

During the autonomous Hermes flight phases, real-time control authority will be delegated by the CMCC-based Mission Director to the Hermes Flight Director. During the rendezvous and docking phase, the crew and the Hermes operations team will execute Hermes operations, and the Free-Flyer operations team its operations, until final docking can be performed by the crew under HFCC flight direction.

The Mission Director at the CMCC will be responsible for resolving issues that could affect the mission objectives or alter the operations planning. During the servicing of the Free-Flying Laboratory by Hermes, the Mission Director will delegate real-time control for most of the servicing tasks to the Laboratory's Flight Director.

DRS operations
The Data-Relay System will provide the following services:
- Relay of data, voice and video to and from low-earth-orbiting spacecraft.
- User spacecraft localisation and orbit determination.

Its principal elements are:
- Two DRS satellites (DRSS) in geostationary orbit, positioned at 44°W and 59°E, thereby providing wide coverage for communications relayed between user spacecraft and the ESA Earth Terminals (EETs).
- The DRS Mission Control Centre (DRS-MCC), which will be an integral part of the Communications Resources Management Centre (CRMC), one of the central facilities at ESOC. It will be responsible for assigning DRS capacity to users and will thus support Space Data Network (SDN) coordination.
- The DRS Operations Control Centre (DRS-OCC), which will conduct all DRS payload operations under the control of the DRS-MCC.
- Two EETs, located in Aussaguel, near Toulouse, and in Oberpfaffenhofen. These represent the gateways between the space-link subnetworks and the ground networks.

The overall system and its utilisation
The decentralised concept on which the In-Orbit Infrastructure ground segment is to be based (Fig. 1) requires careful coordination of the roles and responsibilities of the different facilities to achieve the optimal balance in terms of operability.

The control centres for space elements (HFCC, MSCC, DRS-OCC and CMCC) will be responsible for both the real-time and non-real-time flight-operations activities, including mission preparation, execution and assessment. When the mission involves a space element belonging to an international partner, then their related control centre comes into action.

The space-element support (or engineering) centres (Free-Flying Laboratory Centre, Attached-Laboratory Centre, Hermes Engineering Support Facility) will provide support to their elements for the operational phase. In addition, they will maintain and

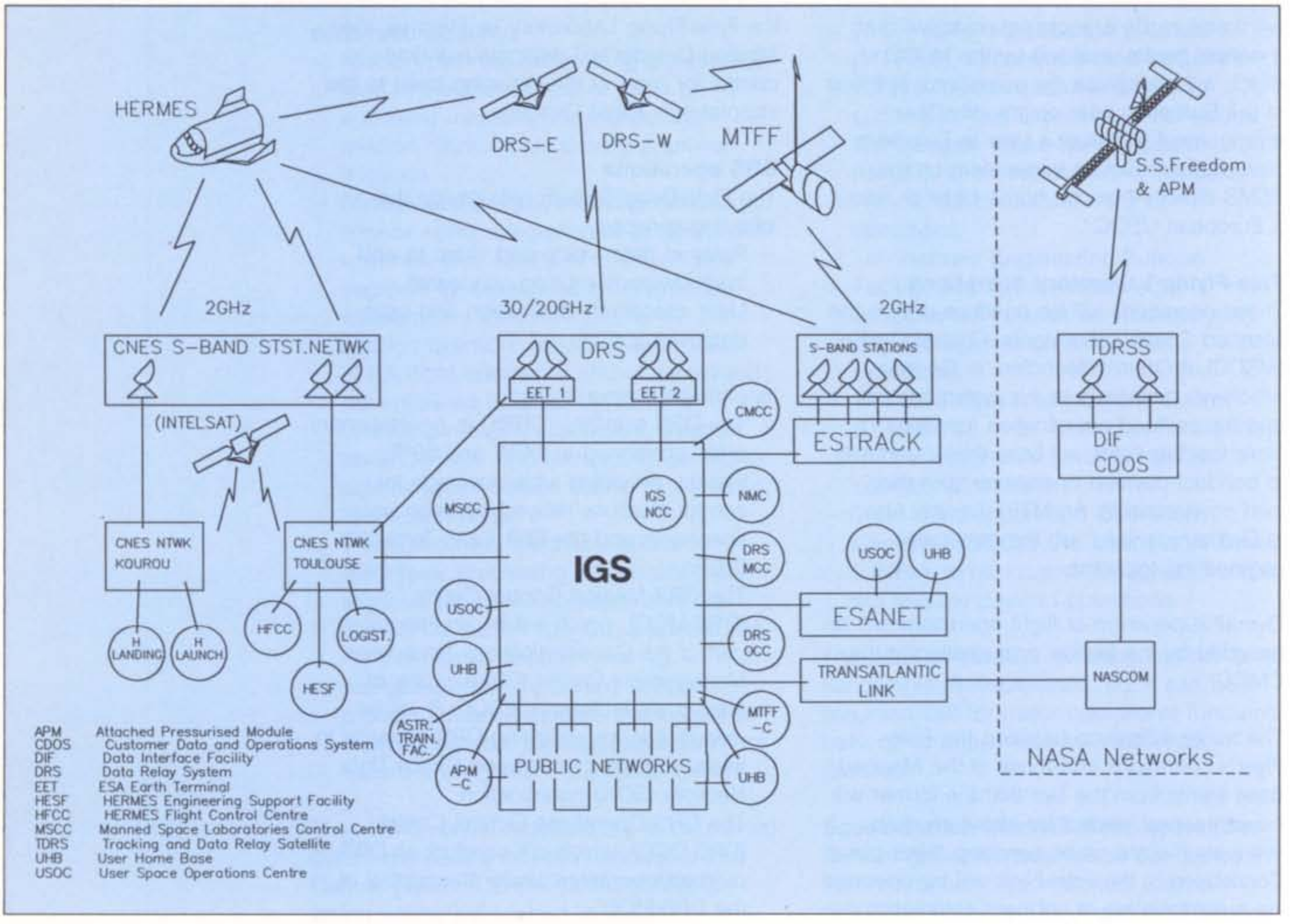


Figure 1. IOI ground-segment facility interconnections

upgrade space-element units, perform logistics for these units, and support payload integration, testing and acceptance. Tools required to accomplish these tasks will be under their responsibility.

The payload-related centres (User Support Operations Centres and User Home Bases) will concentrate on the activities and means to allow users to build and operate their payloads. The ground network will provide them with the communications services needed to access their experiments in space.

The communications-related facilities (Network Management Centre, DRS Mission Control Centre, Interconnection Ground Subnetwork, ESA Earth Terminals, S-Band Stations) will control and manage space and ground communications, ensuring the availability of appropriate communications services.

The Hermes–Columbus servicing-mission operations will be organised as shown in Figure 2. The Mission Director has overall responsibility for the achievement of the mission objectives, for which he receives support from an advisory team.

Communications

IOI communications will involve numerous networks both in space and on the ground, as already indicated in Figure 1. For their interconnection, the two DRS satellites will be used, providing almost continuous coverage with a small exclusion zone (10%). Two ESA Earth Terminals (EETs), one for the Free-Flying Laboratory, the other for Hermes, will receive the return links and transmit the forward links, and they represent the gateways to the terrestrial networks. Each EET will serve as a back-up to the other, to cope with site diversity or outages due to malfunctions.

S-band stations within the ESA Estrack network, or stations in other networks, such as CNES, will also be able to communicate directly with the IOI space elements. With the exception of the Hermes launch and landing phases, S-band station support is foreseen for contingency situations only, due to the very limited contact times (order of minutes).

The forward and return links for the Columbus Attached Laboratory will be routed via the SSMB, with NASA's Tracking and Data-Relay Satellite System providing the

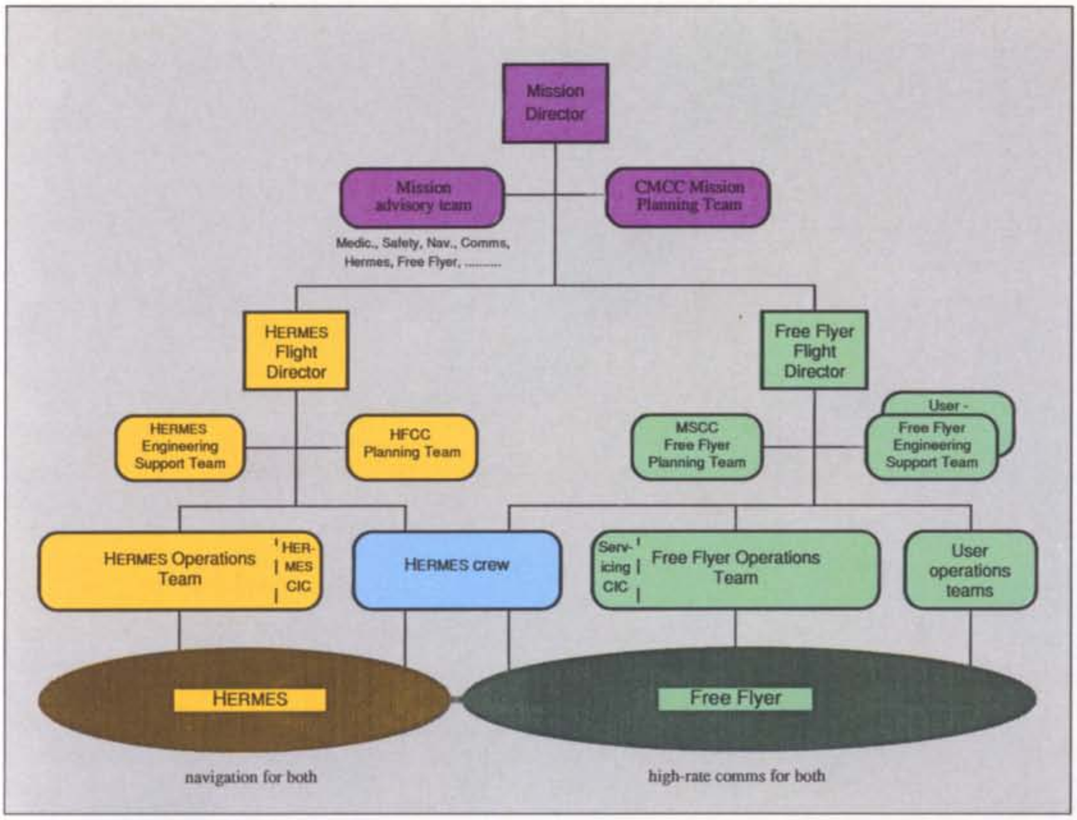


Figure 2. Real-time operations hierarchy during servicing of the Columbus Free-Flying Laboratory by Hermes

interconnection with the White Sands ground station. The European return link carrying all data for European experiments within the Attached Laboratory and the Space Station Manned Base will be routed to the European Control Centres and users.

The three routine operational gateways for IOI space-to-ground links will be the two EETs and the interface with the NASA communications network in the case of Columbus Attached Laboratory data.

The **Communication Resource Management Centre (CRMC)** at ESOC will process all communication service requests centrally and coordinate the allocation of resources.

The **Interconnection Ground Subnetwork (IGS)** will provide the connectivity between the various terrestrial networks and with the space data links (Fig. 3). In the case of Columbus, the IGS will demultiplex the return link at the EET gateways into virtual channels or packets which will be distributed directly to their various destinations.

Mission planning

The mission planning process for the IOI is aimed at providing both the scientific and commercial user communities with a maximum of flexibility and independence, in some cases at the expense of less than optimum use, at least initially, of available resources. The principal reasons for this are the long planned operating lifetimes (some 30 years) for the International Space Station 'Freedom' and the Columbus Free-Flying Laboratory, and the expected large and widely dispersed user community.

The involvement of a user will ordinarily start with the submission of a proposal for an experiment programme. Having gained approval for the programme at the strategic level, and thereby having received an assignment of onboard resources and services, the user's experiment will become eligible for the tactical planning step, the purpose of which will be to set the detailed objectives for a particular mission or 'increment'. The result of these efforts will be documented in the so-called 'Tactical Resources & Operations Plans' (TROPs) and in the related documentation for the SSMB. Once an experiment run has been assigned to a specific increment, the user can assume that the necessary transportation-, communications- and other services will also be available.

For Columbus, the MSCC (in collaboration with the POIC/SSCC for the SSMB) will proceed by assigning the individual experiment runs to specific periods of typically one week within the increment, taking into account the resources needed for each run and the estimated overall availability of resources for utilisation. For generating

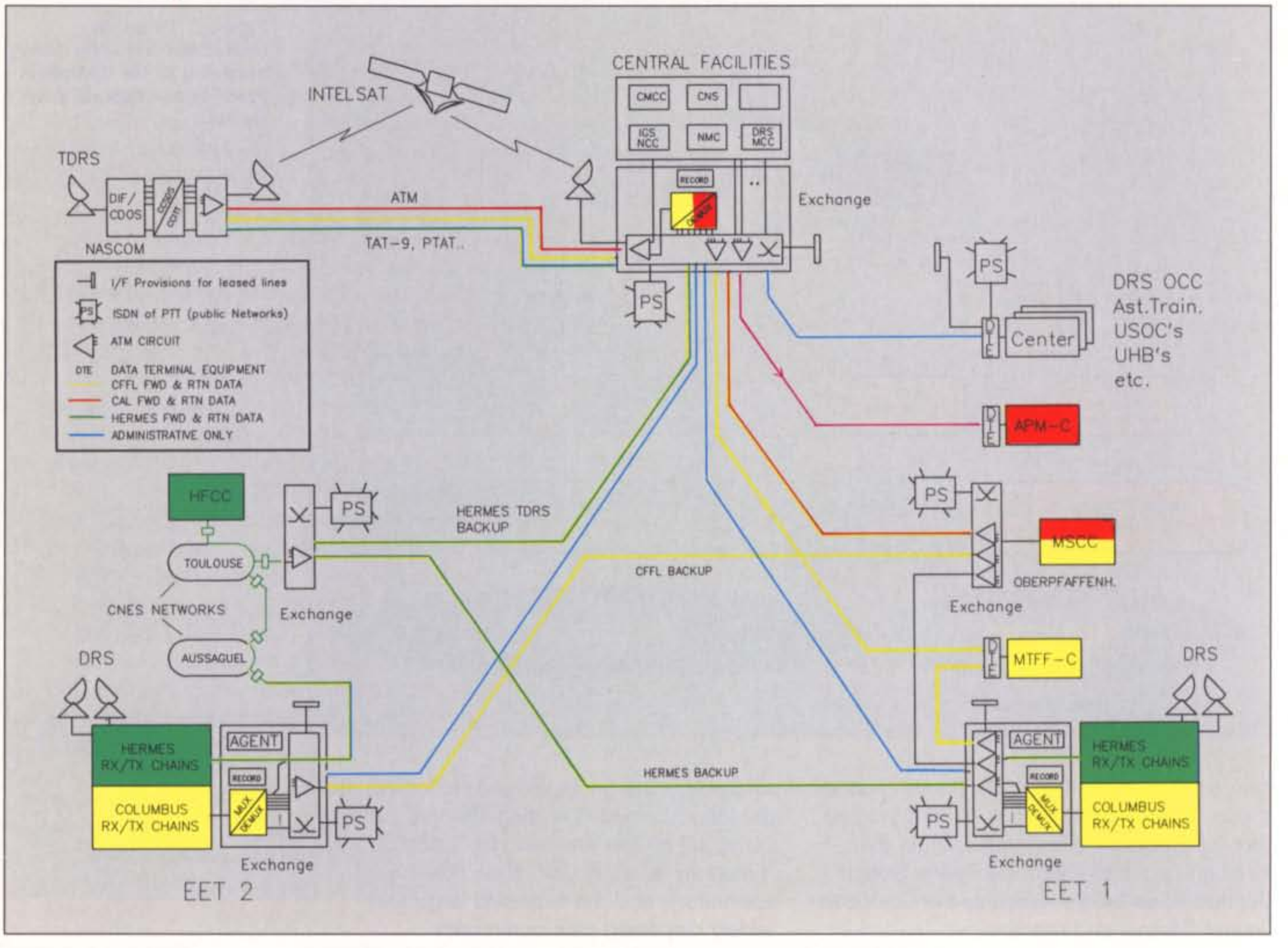


Figure 3. Core of the Interconnection Ground Subnetwork (IGS)

the 'Increment Operations Plan' (IOP), no knowledge will be required of the detailed execution of the experiment runs, other than the resource profiles associated with the various steps of each run.

In the meantime, the user will be able to detail the experiment runs planned to be executed in the increment, in terms of commands to be sent, software to be uploaded, crew interactions needed, etc., provided that:

- all that is being planned for fits within the resources assigned to the individual runs, and
- all commands, uploads, procedures, etc. used are compatible with the corresponding onboard configuration and databases.

Finally, approximately one week before the next operations period commences, the control centres will start to put together the final operations time line, to arrive at the 'Short-Term Plan' (STP). This will record all activities that have to be carried out onboard, whether by the crew or by the onboard automation, and on the ground by the control/coordination centres and related service organisations.

Acknowledgement

The authors would like to thank all those who have contributed to the technical work underlying this article, and especially the industrial System Architect Support Contract team led by ERNO.

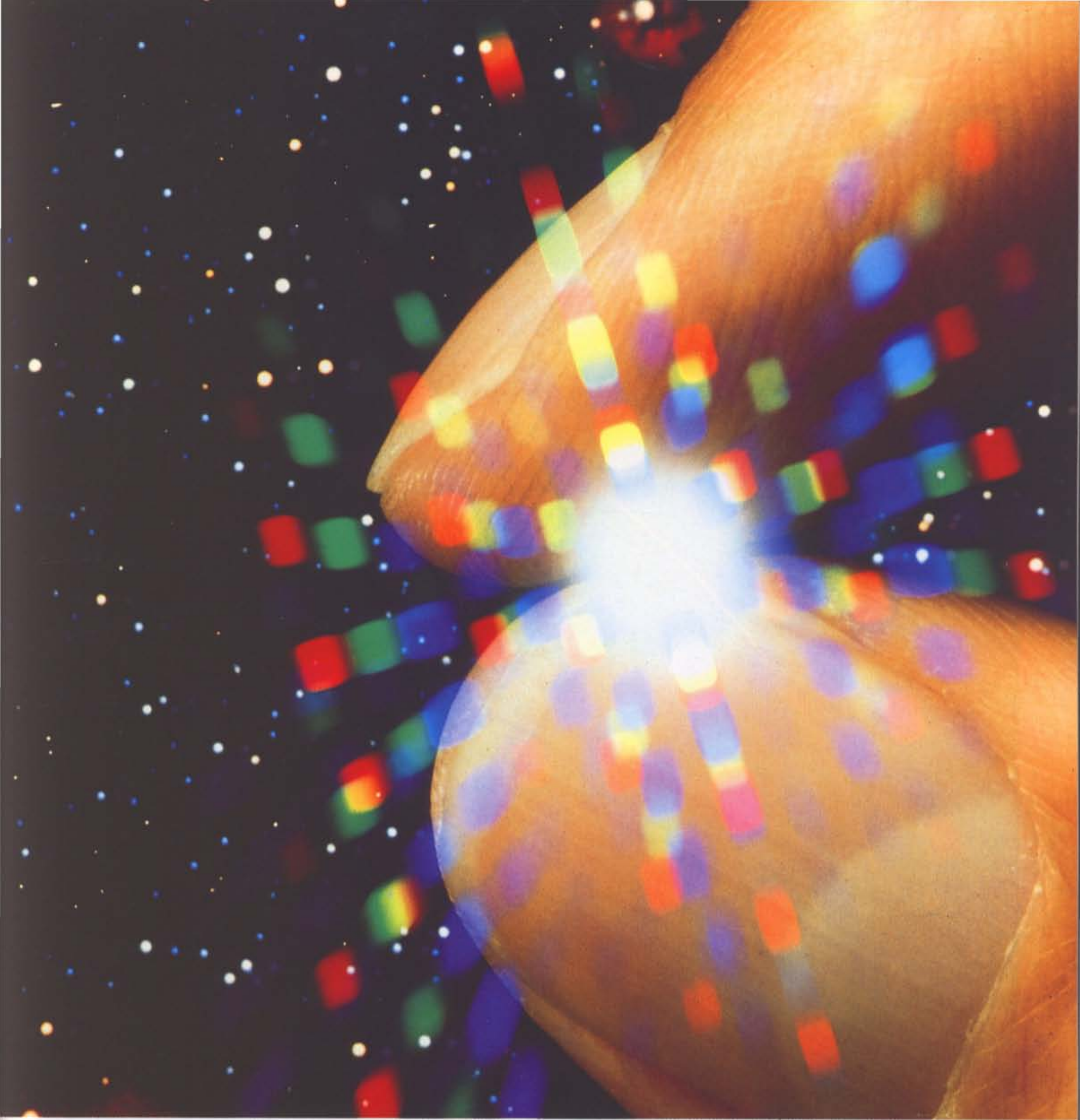
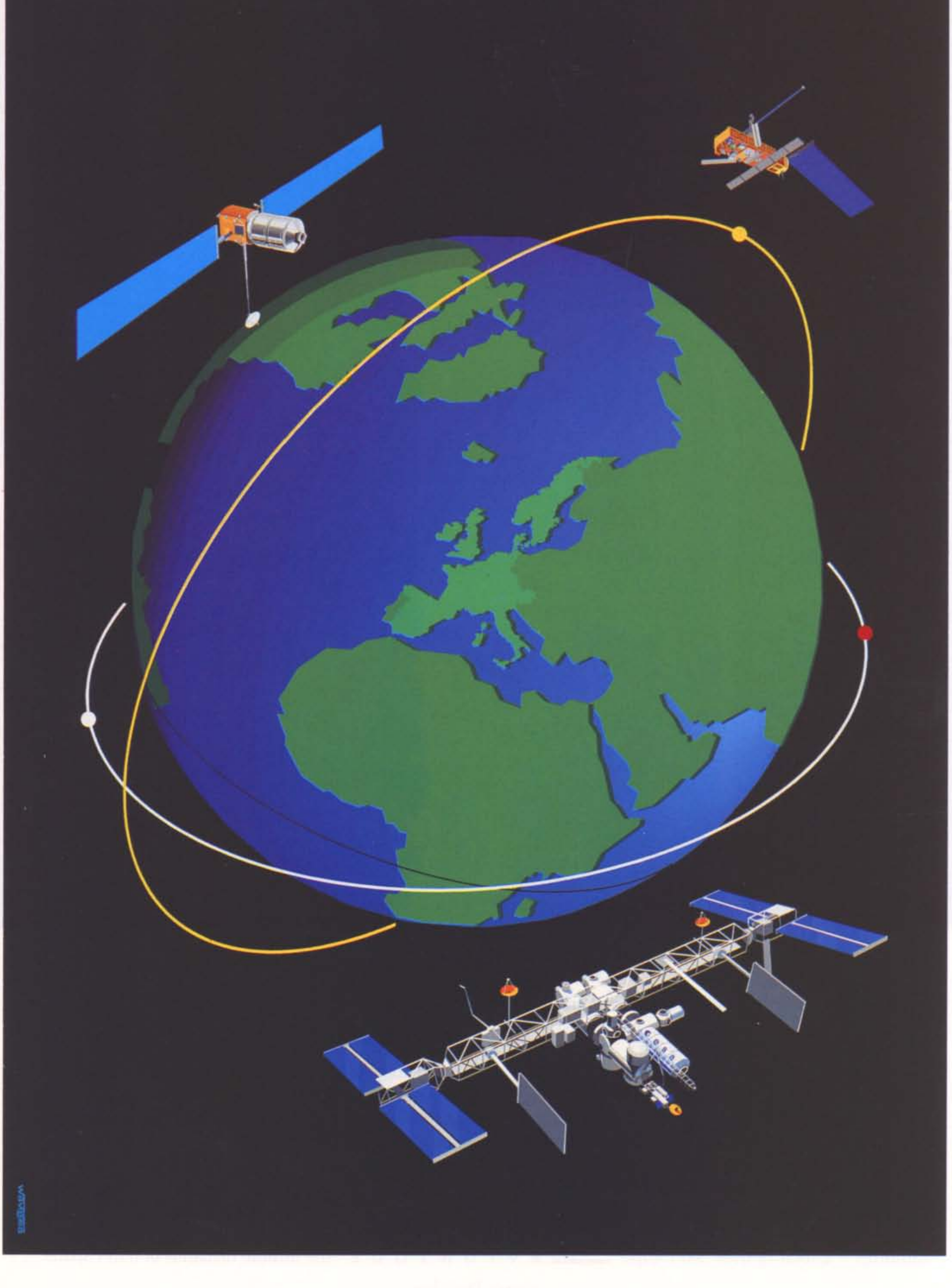


Figure 1. The three space elements of the Columbus Programme



The Columbus Free-Flying Laboratory – A Stepping Stone Towards European Autonomy

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The Columbus Programme

The main objectives of the Columbus Programme are to:

- provide an in-orbit and a ground infrastructure compatible with the needs of European and international users from the mid-1990s onwards
- develop further European capabilities in manned spaceflight
- cooperate with the United States and other partners in an International Space Station, to which Columbus will be Europe's contribution

The Resolution approved by the ESA Council Meeting at Ministerial Level in the Hague in 1987 covers both cooperation with the United States and preparation for European autonomy in specific areas. It 'reaffirms the objectives to prepare autonomous European facilities for the support of man in space, for the transport of equipment and crew and for making use of low-Earth orbit', and 'approves the objective of reinforcing the current capability in order to achieve as far as possible by the end of this century the capability needed ... in order to provide for men living and working in space'. It also 'notes the importance of continuing studies and technology programmes concerning ... the expansion of the European In-Orbit Infrastructure to render it fully autonomous'.

The Columbus Free-Flying Laboratory responds to those objectives and paves the way towards that European autonomy.

- ensure the development of a European capability that will help to achieve autonomy in space in the longer term
- ensure that the technological research and key technological developments required for manned spaceflight and for the wide spectrum of in-orbit operations, both manned and automatic, are carried out.

Columbus is an ambitious, comprehensive, long-term programme embracing several space elements and missions, and involving ground facilities, data-relay satellites and launchers. It is also a programme via which Europe can achieve fruitful cooperation with its international partners, whilst moving towards the stated goal of long-term European autonomy in manned spaceflight.

The Columbus Programme includes three spaceflight elements (Fig. 1):

- The Columbus Attached Laboratory, an integral part of the continuously manned International Space Station 'Freedom'. This Laboratory will be launched by the Space Shuttle in the third quarter of 1997.
- The Columbus Free-Flying Laboratory, which will be put into orbit near the Space Station. It will be free-flying for periods of six months at a time, after being launched by Ariane-5 in the third quarter of 1998. It will have no permanent crew, but will be visited twice a year by astronauts using Hermes.
- The Columbus Polar Platform, an unmanned Earth and space observation vehicle that will be put into a polar orbit, carrying instruments requiring direct access to the space environment. It will be launched by Ariane-5 in the second quarter of 1997.

The Columbus flight elements therefore range in nature from an automatic unmanned platform to a permanently manned laboratory, thereby providing investigators with opportunities for a wide variety of scientific and technological experiments.

The need for a manned orbital infrastructure

At the beginning of the 1970s there was much discussion about the need for Europe to embark on an autonomous launcher programme. The temptation to concentrate funds on the development of satellites and to pay for the use of 'foreign' launchers was great. It can be seen today that Europe's resolve at that time to establish its own space-transportation infrastructure not only gave birth to a healthy and competitive European launch industry, but also helped to foster similarly competitive positions for Europe first in the field of telecommunications, and shortly thereafter in the Earth-observation domain.

There is no doubt, looking back, that mastery of its own launch capabilities was a condition sine qua non for Europe, and in particular for its industry, to play a leading role on the international scene. Not everyone was convinced of that at the time of the decision, or saw a bright future for the emerging discipline of telecommunications, but fortunately there were sufficient Member States with the vision and faith in the future to embark on what is now a major element of European space policy.

Twenty years later, one can perceive that new mission opportunities, the evolution of space systems, and the progress in operations will lead to the development of an orbital infrastructure with man as an essential asset, complementing the transportation infrastructure. Man's interventions in space over the years have been highly successful (Skylab, SMM, Salyut-7, Leasat, Westar, etc.). The trend towards increasing complexity in space systems is likely to make in-orbit repair operations indispensable. The existence of an orbital infrastructure will make such interventions easier, and the Space Telescope, for example, could probably be repaired if such an infrastructure were in place now.

At the same time, the size and scope of space systems for certain types of missions is likely to increase substantially, thereby exceeding the capabilities of single launches. The possibility, for example, of transferring complexity from the Earth segment to the space segment for certain classes of missions (e.g. telecommunications antenna farms) might lead to very large systems being assembled in low Earth orbit prior to making a 'smooth transfer' to their final operating orbits. In other words, an 'orbital transportation node' is likely to become necessary at a certain point as a complement to the next generation of space transportation systems.

Commercial microgravity activities, following on from the planned experimentation phase with Columbus, could become one of the essential customers of the manned space infrastructure. Other possible but as yet more speculative missions would also require the services of a manned orbital infrastructure, such as the processing or disposal outside the biosphere of materials giving rise to increasing concern in the context of protecting the Earth's environment.

Other large-scale activities that could be contemplated in the more distant future such as the exploitation of extraterrestrial resources, new sources of energy, etc. would be unthinkable without the support of a manned orbital infrastructure. Only a manned infrastructure will be able to provide the flexibility needed to cope with these types of space activities, with human brainpower still being needed for a long time to come for monitoring, intervening, maintaining and repairing, despite the expected advancements in automation and teleoperation.

What will be needed?

Despite the great uncertainties involved in such large application perspectives, the potential stakes are so high that Europe cannot but prepare itself now, if it is not to run the risk of permanently endangering its place in the fiercely competitive commercialisation of space that is likely to dominate the next century.

On the other hand, there is such a lack of definitive requirements at the current time that there is no question of embarking today on a specific design for such an orbital infrastructure. Only a step-by-step approach, with each element added being able to fulfil a series of missions, can be realistically considered, building towards the future capability at a pace commensurate both with technological progress and Europe's financial capabilities.

Such a step-by-step approach leaves sufficient flexibility to be able to adapt the scenario to the future evolution of space activities. What is needed then is a thread of continuity that links the successive developments technologically. The Columbus Free-Flying Laboratory, serving as a core providing the essential resources, is ideally suited for that role.

The Columbus Free-Flying Laboratory

This Laboratory is designed to accommodate the material-science, fluid-physics and life-sciences research domains, all of which call for relatively long periods of undisturbed microgravity. A 6.2 m long, pressurised module of 4.5 m diameter can accommodate payloads in the equivalent of 16 single racks, and a replaceable resource module provides 20 kW of power and a data-transmission capacity (downlink) of 100 Mbit/s.

The Laboratory will be launched from Kourou, in French Guiana, by an Ariane-5 vehicle directly into its operating orbit at between 320 km and 480 km altitude (final orbit depending on Space Station altitude). Its weight at launch will be 17 900 kg, including an initial 1000 kg of payload and sufficient propellant for a five-year mission including nine Hermes visits and one visit to the Space Station, plus one backup visit.

The Laboratory will be serviced once every six months by Hermes (Fig. 2), and once every five years at the Space Station (by manoeuvring it to the Station using its own propulsion system), where it is planned to exchange the complete resource module. The twice yearly Hermes servicing mission, lasting just seven days, provides for internal payload and subsystem servicing, as well as possible contingency servicing of small external items.

Hermes will rendezvous and dock with the Free-Flying Laboratory when the latter is at the lowest point of its orbit. All Free-Flyer operations will be under direct European control, including the Hermes/Free-Flyer composite operations during the Hermes servicing visits. Europe therefore has to develop and put in place all the necessary means and procedures required to master manned orbital intervention for its own elements (see companion article on pages 21–26 of this Bulletin).

The role of Columbus in an autonomous scenario

Through its development of the Free-Flying Laboratory, Europe will establish a system that is essentially the initial core element of the future infrastructure, providing high power, thermal dissipation, stabilisation, data processing and transmission, pressurised volume, and essential docking features. All plans being developed within the preliminary studies on the 'European Manned Space Infrastructure' (EMSI; Fig. 3) rely on a Free-Flyer as a starting point. In this respect, it can also be regarded as the first link in the orbital infrastructure, to be complemented with additional elements (Interconnecting Element, Hab/Lab Module, etc.) as and when necessary.

The Free-Flying Laboratory should therefore not be judged in isolation, but in the context of its future role in the long-term scenario of space developments. Not only is it an essential element within the Columbus Programme, providing an exceptional environment in which to perform microgravity experiments, it is also the central element of the future autonomous orbital infrastructure that Europe needs to develop for the next century to complete its space transportation capabilities.

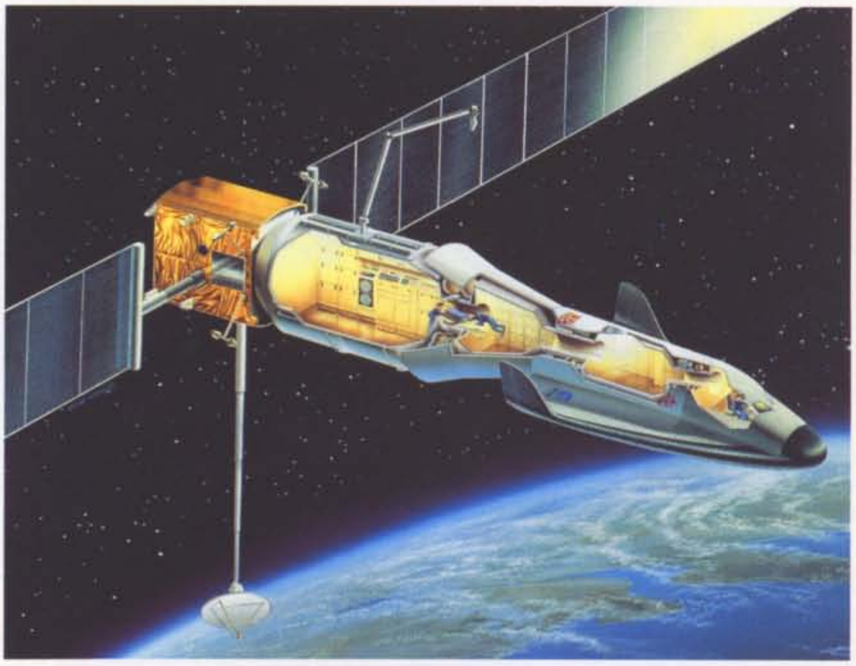


Figure 2. Hermes docked with the Columbus Free-Flying Laboratory (courtesy of D. Ducros)

Preparation for the autonomous phase

By the end of the decade, Europe will have substantially reinforced its expertise in manned space systems (high power and heat rejection; rendezvous and docking; robotics and tele-manipulation; re-entry, and all the ground infrastructure necessary to support manned missions, from selection of crew to landing). However, it will still need to master another critical area: namely, all the techniques necessary to allow humans to live under conditions of weightlessness and isolation for long periods.

The meeting of all of the crew's personal needs (food, hygiene facilities, etc.) aboard the International Space Station 'Freedom' are designated NASA responsibilities, as are all safety aspects including health matters and all Extra-Vehicular Activity (EVA). In addition, NASA is responsible for setting the medical standards and requirements for Freedom's astronauts.

In the case of Hermes, ESA will have full responsibility for ensuring the health, safety and productive performance of the European

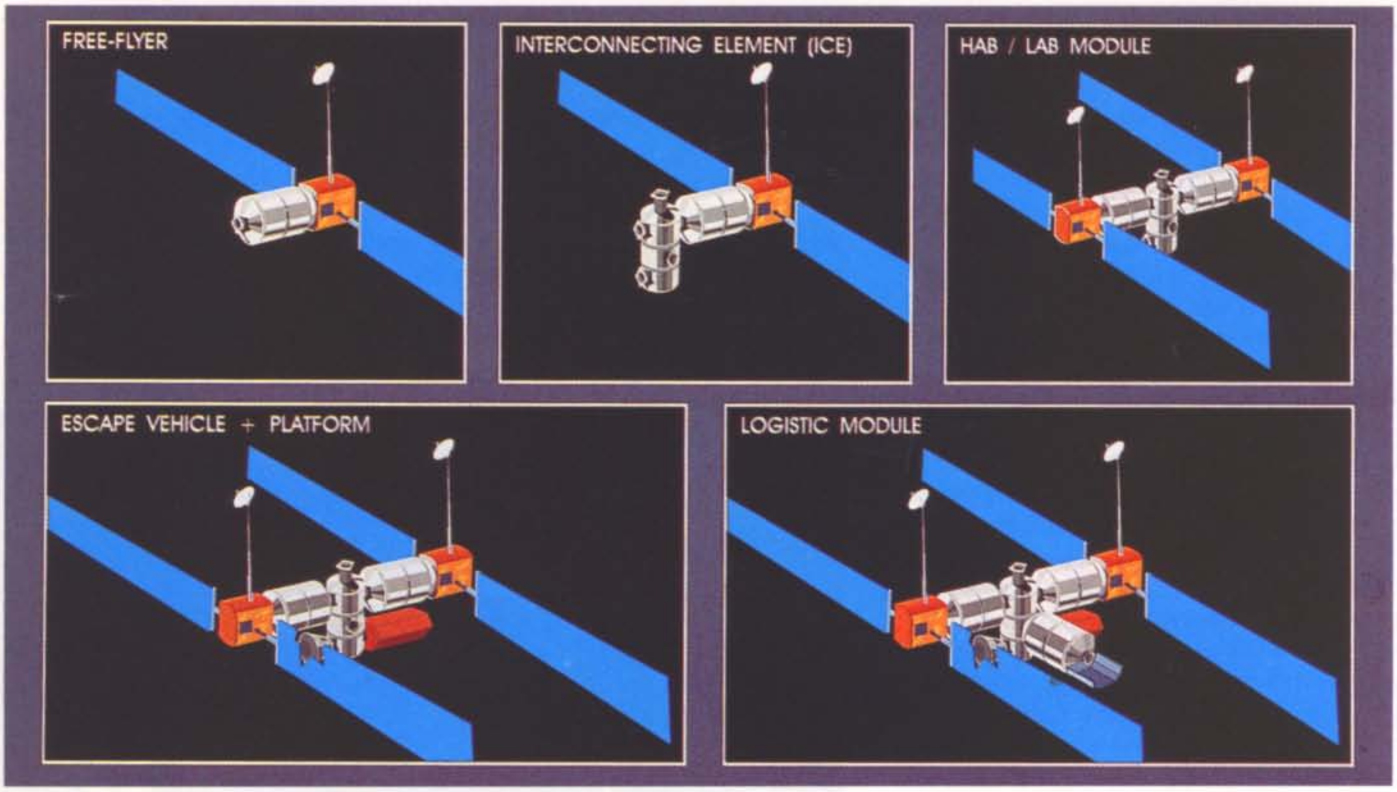


Figure 3. Study concept for the future European Manned Space Infrastructure (EMSI), showing a five-stage build-up to a permanently manned European Space Station, using Habitation and Laboratory Modules based on the Columbus Free-Flying Laboratory

Astronauts during their stay in orbit, including EVA. However, the shortness of the Hermes missions, each of which will lasting about seven days, considerably alleviates the problems associated with living under space conditions, i.e. only limited countermeasures are necessary to ensure astronaut health and safety. The solutions adopted for Hermes will therefore generally not be applicable for the long-duration missions of the future, and the expertise acquired through Columbus will also be limited in this domain.

As the mission durations increase, the physiological and psychological problems encountered by the crews will be much more substantial. By the end of the century there will still be large gaps in Europe's knowledge of human factors associated with long-duration spaceflight, which will leave it far from mastery of its stated objective of achieving autonomy. Consequently, ESA is in the process of preparing a proposal for a dedicated EMSI Preparatory Programme which, in parallel with the development of the Columbus Free-Flying Laboratory, will lay the groundwork in these new (for Europe) areas, before embarking upon the next development phase.

Conclusion

The same rationale that led Europe to undertake development of its own space-transportation capability with Ariane will lead it to establish its own orbital infrastructure with a manned capability. The fact that Europe's ability to participate in the commercialisation/industrialisation of space in the coming decades is at stake will dictate the choice. By the beginning of the next century, there will be two classes of space power: those who have the capability and will therefore master its application, and those who do not. Europe cannot afford to find itself in the latter category.

Mastery of all of the human problems associated with long-duration space missions will take some considerable time, and Europe needs to establish an intellectual infrastructure and support a research programme in those 'human-in-space' disciplines where we currently have no expertise.

Meanwhile, from the hardware and operations standpoints, the Columbus and Hermes Programmes will provide the pillars on which Europe must build its In-Orbit Infrastructure. The Columbus Free-Flying Laboratory represents the first link in the chain of development leading to the establishment of a European Manned Space Infrastructure. Its role, therefore, is not only to satisfy the microgravity community to the maximum extent possible by providing them with a better environment in which to work than the Space Station itself can offer, but also to pave the way for the future. Hence it represents Europe's bridgehead to the 21 st century.

Figure 1. Artist's impression of the new 'European Astronauts Centre' (EAC), to be built near Cologne, Germany

The New European Astronauts Centre

A. Ripoll, K. Damian, W. Peeters & F. Rossitto
European Astronauts Centre (EAC), Cologne, Germany

At the ESA Council Meeting at Ministerial Level in The Hague in November 1987, Europe took the far-reaching decision to establish a manned 'In-Orbit Infrastructure', based on its Ariane-5, Columbus, and Hermes Programmes. It was decided at the same time to cooperate with the United States, Japan and Canada in the framework of the International Space Station 'Freedom' Programme. As a result, ESA was entrusted with the task of building up a 'European Astronauts Centre' (Fig. 1), coordinating the establishment of the necessary facilities for astronaut training, and establishing a 'European Astronaut Corps'.

Introduction

The 'European Astronauts Policy', endorsed by an ESA Council Resolution*, is founded on the following principles:

- It should represent a unified approach, endorsed by all Member States, avoiding wasteful duplication or competition.
- It should take ESA's role and responsibilities fully into account.
- It should also make use of the expertise and resources of all Member States, particularly those that have already accumulated manned-spaceflight experience.

It foresees the setting-up of a single European Astronaut Corps, all of whom will be governed by the same rules of selection, training and flight assignment. Once selected, the 'European Candidate Astronaut' will undergo his/her first basic and then more specialised training. Once qualified, the Candidate Astronaut will be nominated a 'European Astronaut' and a 'Member of the European Astronaut Corps' and will be assignable to forthcoming missions.

As the European Astronauts will be mainly concerned with the operation of Columbus elements, including their payloads, and the conduct of Hermes missions, two types of specialisation are foreseen, namely as a 'Spaceplane Specialist' or a 'Laboratory Specialist'. The former will be assigned to Hermes missions as Commanders or Pilots. The Laboratory Specialists will be assigned to the Columbus Attached Laboratory/Space Station 'Freedom' as a Station Operator or Station Scientist, or to the Hermes/Columbus Free-Flying Laboratory as a Mission Engineer.

Flight assignments will be decided by ESA's Director General. In the case of Space Station 'Freedom' astronauts, NASA will be consulted. Once a flight assignment has been made, the astronaut concerned will undergo a mission-specific training programme under the authority of the European Astronauts Centre (EAC).

A major objective of the European Astronauts Policy is equitable representation of the Agency's Member States in flight crews over a reasonable period of time.

Astronaut selection

Flight opportunities

The schedule for the establishment of the European Astronaut Corps is driven by the requirements of the several flight opportunities for ESA Astronauts within the framework of the Columbus and Hermes Programmes between 1993 and 1997.

The Columbus Preparatory Mission flight opportunities include both Eureca and Spacelab flights. Eureca, the unmanned European Retrievable Carrier, will be launched and retrieved, after a six to nine month orbital flight, by the Space Shuttle. For the first Eureca mission, scheduled in 1991, Claude Nicollier will form part of the Shuttle crew, as the first European astronaut to serve as a Mission Specialist, involved in the Carrier's deployment.

A number of Spacelab missions are planned, some with flight opportunities for European astronauts, on which advanced experimental facilities for Space Station 'Freedom' and

* ESA/C/LXXXVII/Res.1(Final)

Columbus elements will be tested. The first flight of the so-called 'International Microgravity Laboratory' (IML-1), scheduled for the early 1991, will give Ulf Merbold the opportunity to fly for the second time, as Payload Specialist.

The flight opportunities for European astronauts on International Space Station 'Freedom' itself will begin with the launch and assembly flight for the Columbus Attached Laboratory. Once the Station is fully operational, a crew of eight will man it in three-monthly cycles. ESA will provide an average of one crew member out of the eight.

Table 1. Summary of selection criteria

General requirements
Applicants may be male or female. They must be nationals of an ESA Member State or of an ESA Associate State involved in an ESA manned space programme. For the present selection, the preferred age range is 27 to 37. Applicants must be within the height range of 153 to 190 cm. They should speak and read English. Applicants must possess a University Degree (or equivalent) in Natural Sciences, Engineering, or Medicine, and preferably have at least three years post-graduate related professional experience (for Laboratory Specialist), or possess a test-, military-, or commercial-pilot's licence and have at least three years of professional experience (for Spaceplane Specialist).

Medical requirements
Compliance with medical criteria is mandatory. Applicants should have a satisfactory medical history and be in a sound state of health, have a normal weight, and be of normal psychiatric disposition. A severe history of motion- or air-sickness may result in disqualification.

Abnormally high dosages of any medication may be considered a disqualifying factor.

The applicants must be prepared to provide a full family and personal history and permit the collection of further information if deemed necessary by the examining medical body. They must also be prepared to participate in extensive medical screening, including internal examinations. In addition, certain tests will be performed to evaluate the applicant's bodily system (muscular, cardiovascular and vestibular). These tests will employ such facilities as: centrifuges, rotating chairs, pressure chambers, and aircraft. All information provided will be treated as confidential.

Psychological requirements
The objective of the psychological tests is to ensure that the Candidate Astronaut will be able to cope with the expected occupational demands (which may not have been faced previously in their careers) in an efficient and reliable manner. Their activities, during the extensive training phase and during spaceflight, will have to be conducted under a certain degree of stress and in co-operation with other crew members (male or female).

General characteristics expected of the applicant include good reasoning capability and memory, good concentration, and good aptitude for spatial orientation and manual dexterity. The applicant's personality should be characterised by high motivation, good flexibility, gregariousness, empathy with fellow workers, low level of or disposition towards aggressiveness, and sound emotional stability.

Professional requirements
The applicant's scientific and technical background and ability will be scrutinised by the ESA Evaluation and Interview Committee. The Candidate Astronaut must be well versed in the scientific disciplines and have demonstrated a superior capability in applicable fields, preferably including operational skills.

A number of development flights are also foreseen during the Hermes Development Programme, with the objective of validating Hermes' aerodynamic characteristics and checking approach and landing procedures.

The first Hermes qualification flight (H001), planned for early 1998, will be unmanned. The first manned flight (H02), in early 1999, will be the first of a series of manned qualification and servicing verification flights.

The Hermes missions to the Columbus Free-Flying Laboratory, which will be launched by Ariane-5 in 1998, will constitute the core of the Hermes operational programme. Hermes will service this free-flyer for the first time in 1999, and thereafter will revisit it on two flights a year, each of nominally 12 days duration. These servicing missions could later be extended to 3 to 4 weeks.

Selection procedure and schedule

The overall selection procedure is broken down into:
- Preselection in ESA Member States
- ESA selection.

Major aspects to be considered are the applicant's ability to meet the medical criteria, psychological suitability, and scientific and technical competence. The Member States will normally propose not less than three, and no more than five, applicants to go forward to the ESA selection stage.

The ESA selection process (Figs. 2 & 3 and Table 1) is divided into four steps:

Step 1: An individual file is set up for each applicant proposed by a Member State, which initially comprises a medical history and scientific/technical questionnaires filled in by the applicant during the national preselection process. The applicant undergoes psychological suitability tests and completes a further detailed scientific/technical questionnaire. The applicant is not interviewed at this stage.

Step 2: Based on a review of the applicants' files, the ESA Evaluation and Interview Committee chooses the short-list to be interviewed. The medical selection tests are also carried out at this interview stage. A report is drawn up on each candidate seen by the Committee. The individual's file is transmitted, together with the Committee's

Figure 2. Procedure for pre-selecting European Candidate Astronauts in ESA Member States

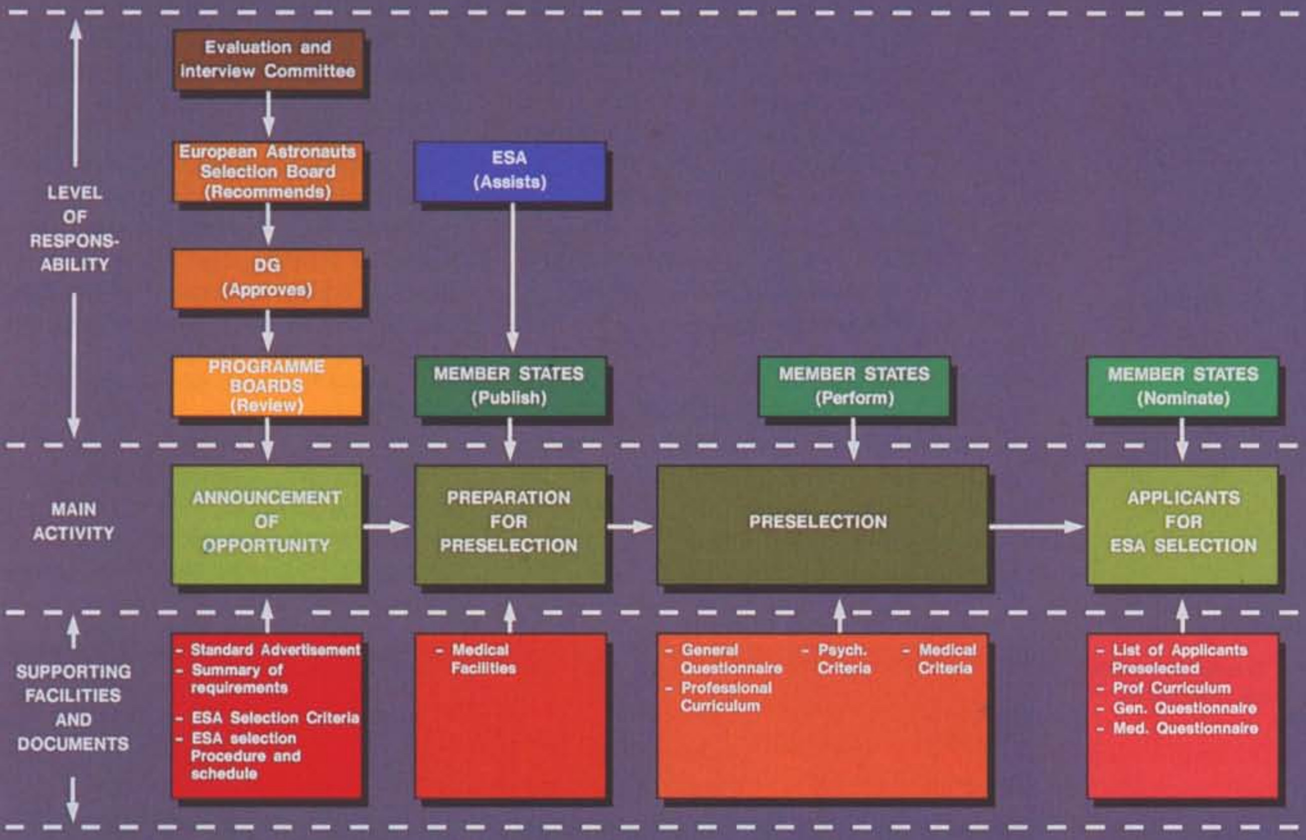
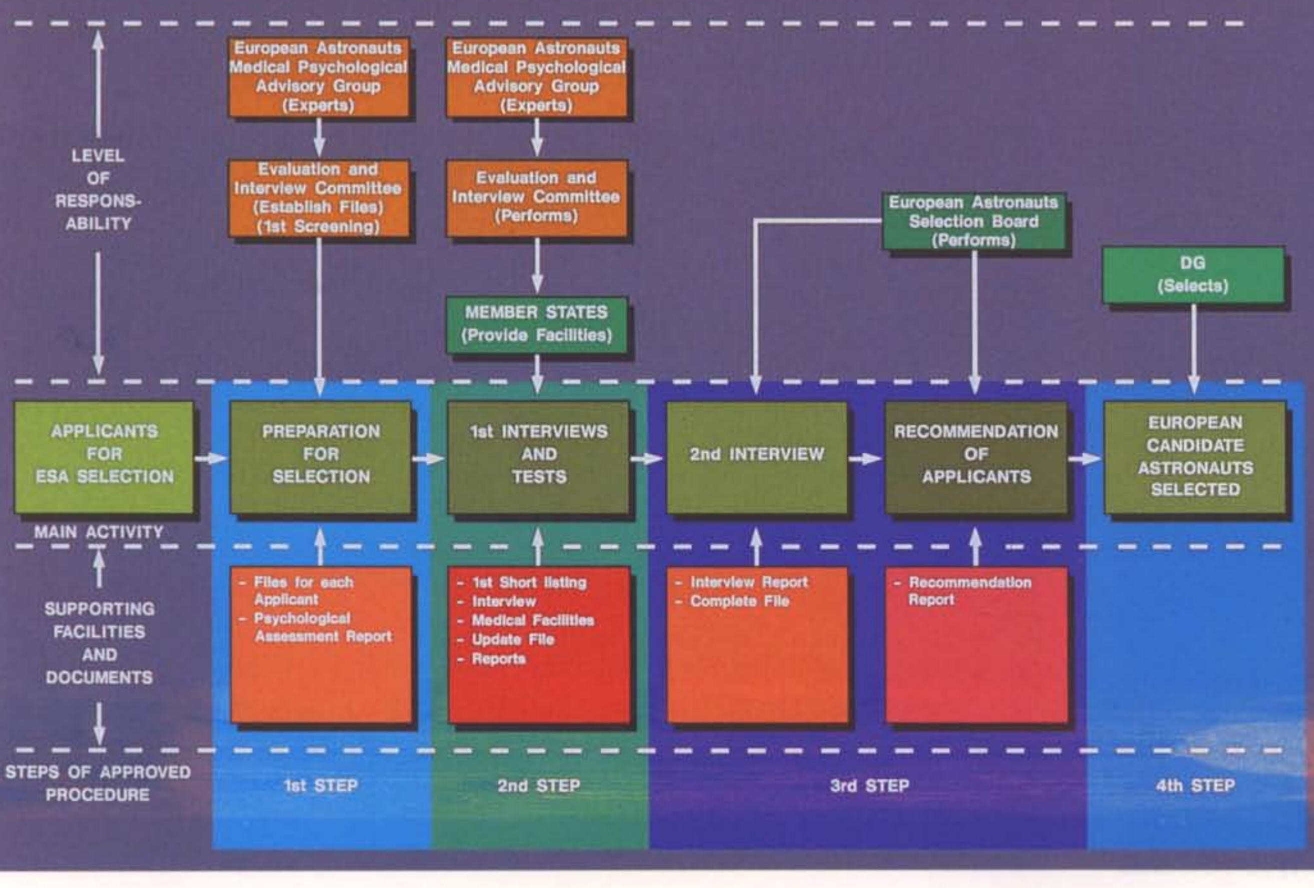


Figure 3. Procedure for final selection of European Candidate Astronauts by ESA



report, to the European Astronaut Selection Board.

Step 3: The European Astronaut Selection Board reviews the files and reports, interviews those applicants considered suitable, and submits its recommendations on the applicants to be retained, in order of priority, to ESA's Director General.

Step 4: Final selection of the European Candidate Astronauts by ESA's Director General.

The overall schedule (Fig. 4) shows the main preparatory activities for the selection procedure, which was initiated by the Agency's Director General on 1 June 1990 with the issuing of the Announcement of Opportunity.

Astronaut training

The manned or man-tended elements of the European In-Orbit Infrastructure, Columbus and Hermes require the services of astronauts with specific qualifications and specialisations.

The Spaceplane Specialists will primarily fly and operate Hermes. They will serve as Commander and Pilot, the former being responsible for the overall mission's execution, control and safety, and the latter being in control of the vehicle and its systems. Depending on the nature of the mission, they may also be involved in servicing tasks.

The Laboratory Specialists, on the other hand, will be responsible for the servicing of systems and payloads on Space Station 'Freedom', including those of the Columbus Attached and Free-Flying Laboratories.

Figure 4. Overall schedule for European Astronaut selection

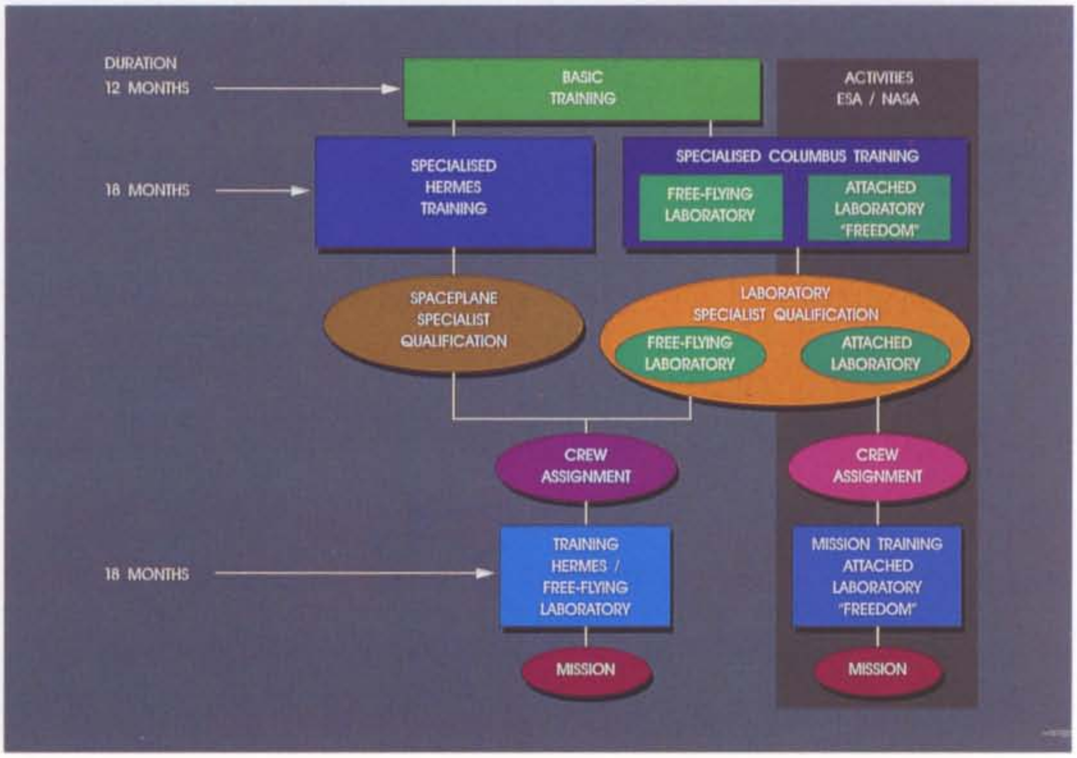


Figure 5. The training cycle for European Astronauts

The European Astronauts on the International Space Station will have one of two roles, namely Station Scientist or Station Operator.

The Laboratory Specialist responsible for the Hermes Free-Flyer servicing missions, called the 'Mission Engineer', will have primary responsibility for the servicing tasks and will be supported by the spaceplane's Commander and Pilot.

Training concept

The training concept presented in Figure 5 is based on the qualifications and specialisations required by the various mission scenarios described above. Following their selection and recruitment, the Candidate Astronauts will receive basic training for a period of one year, during which they will be familiarised with space-science, space-technology and space-operations concepts and approaches. In addition, they will receive biomedical and pilot-proficiency training.

In the subsequent 18-month specialised-training phase, the careers of Laboratory Specialists and Spaceplane Specialists will diverge. Training for the International Space Station will take place in the USA for common system operations, the NASA Laboratory and NASA payloads, and in Europe, Japan and Canada for the elements and payloads contributed by these partners.

The Mission Engineers to be responsible for Hermes free-flyer servicing activities will receive detailed training on the Columbus Free-Flying Laboratory's systems and payloads, as well as Hermes system training. The specialised training for Spaceplane Specialists will focus on Hermes system operations and piloting, and will also include some free-flyer systems training.

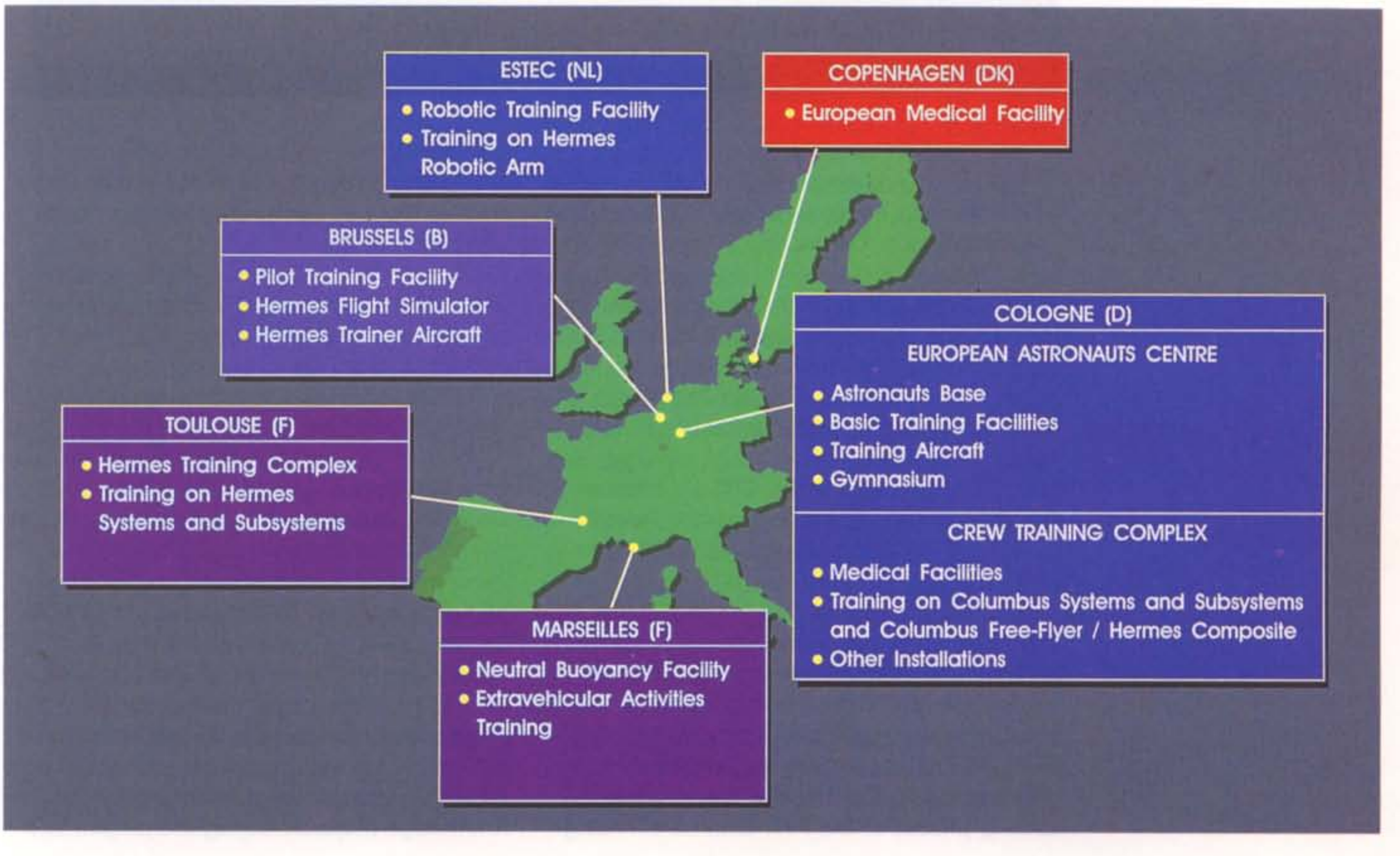
The crew assigned to a specific mission will also receive 'mission training' as a team for a period of 18 months. Again, the International Space Station crew will be trained at various training sites in the USA, Europe, Japan and Canada. The crew for the Columbus Free-Flying Laboratory's servicing by Hermes (Commander, Pilot and Mission Engineer) will be trained at the European training facilities.

Training facilities

The European astronaut training facilities will be based on a decentralised concept, with a further six facilities supporting the EAC itself (Fig. 6):

- a Crew Training Complex (CTC), near the EAC in Cologne, Germany (Fig. 7);
- a Hermes Training Complex (HTC), in Toulouse, France;
- a Neutral-Buoyancy Facility (NBF), in Marseille, France;
- a Pilot Training Facility (PTF), in Brussels, Belgium (Fig. 8);

Figure 6. The European facilities for astronaut training



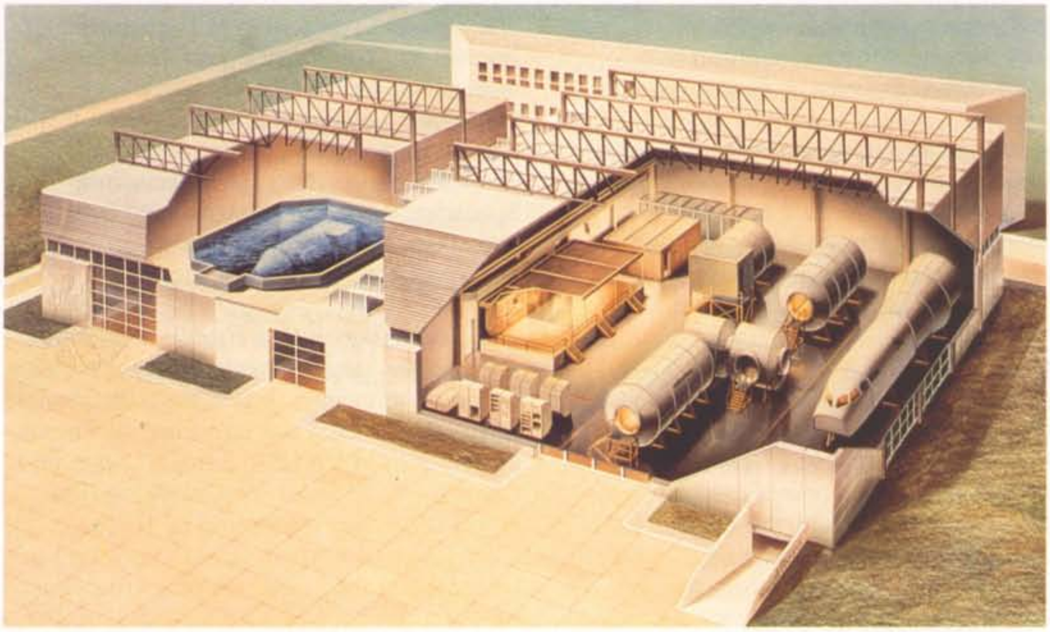


Figure 7. Artist's impression of the Crew Training Complex (CTC), to be built near Cologne, Germany

Figure 8. Artist's impression of the Pilot Training Facility (PTF), to be built near Brussels, Belgium

- a Robotic Training Facility (RTF), at ESTEC, in The Netherlands; and
- a European Medical Facility, in Copenhagen, Denmark.

The CTC will provide both Columbus and Hermes specialised mission training and will support the EAC in some areas of basic training. It will also provide the Attached-Laboratory training for all International Space Station astronauts. The Hermes/Free-Flyer composite simulator at the CTC will provide the specialised and mission training needed for internal servicing of the Columbus Free-Flying Laboratory.

The other European training facilities are dedicated to Hermes training. The HTC will include Hermes system and subsystem simulators. A spaceplane flight simulator as well as a Hermes training aircraft will provide pilot training for the Hermes descent and landing phases at the PTF. External-servicing training will be provided at the NBF in a large water tank with submersible mockups. Hermes Robotic Arm (Hera) training will be conducted at the RTF.

Training at other facilities – such as launch and landing sites, engineering support centres, and at user operations centres – will also be required from time to time.

Organisation

Given the decentralised concept that has been adopted for the European Astronaut training policy, a centralised administrative and organisational management structure for the new European Astronaut Corps and their facilities was of paramount importance. With the wide distribution and delegation of training tasks foreseen, a central European centre of expertise for manned mission aspects needed to be established. Knowledge acquired during the preparatory

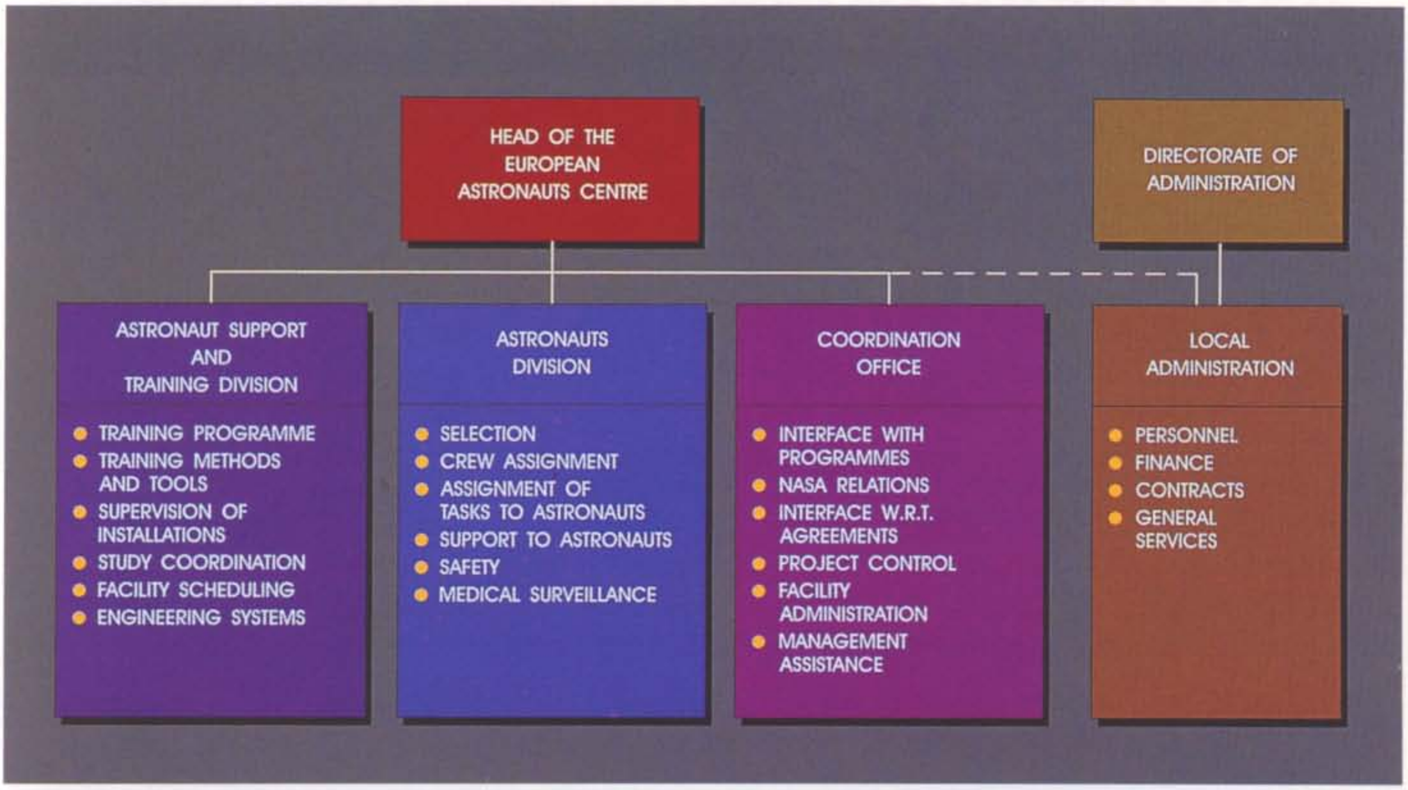


Figure 9. The organisational structure of the European Astronauts Centre (EAC)

missions also needs to be compiled centrally, to facilitate proper feedback to the evolving training curriculum.

Aside from these technical requirements, the need for a 'home base' for Europe's future astronauts, who will have to travel extensively during their training, cannot be neglected.

The organisational structure for the 'European Astronauts Centre' has therefore been tailored with centralised management of all future European astronaut activities as its major objective, embracing (Fig. 9):

- Basic management of the Astronaut Corps.
- Management of training.
- Coordination with other entities.
- Administrative on-site support.

Given the existing infrastructure at DLR in Cologne, it was decided to locate the EAC establishment close by. The formal Host Agreement between Germany and ESA for the EAC was signed on 10 May 1990.

This Agreement provides, inter alia, for a 10 000 m^2 site near Cologne, in the vicinity of DLR, with easy access to Cologne Airport. The design of a suitable building to house the new organisation has already been initiated, with the first phase of construction to be completed during the second half of 1992, in order to meet the agreed recruitment and training schedules.

This first building will allow 70 staff to be housed with the minimum infrastructure needed to cover the transitional phase up to 1995.

The coordinating role of the EAC

Aside from its prime role as 'home base' for all European astronaut activities, the EAC will also ensure proper coordination and overall availability scheduling of the various specialised facilities distributed throughout Europe. A set of centralised requirements is in the process of being established to ensure the proper coherence between facilities in terms of communications, data retrieval and exchange, and documentation.

The heavy workload imposed on the Candidate Astronauts during training should not be further increased by a need for continuous adaptation when travelling from one centre to another. A degree of standardisation that facilitates the settling-in and familiarisation process is therefore one of the basic requirements.

The close coordination needed with the Columbus and Hermes Programmes, and with external agencies, will also constitute an important function within the EAC.

Schedule

The timing of the coming on-stream of the various functions and facilities is driven by two main factors:

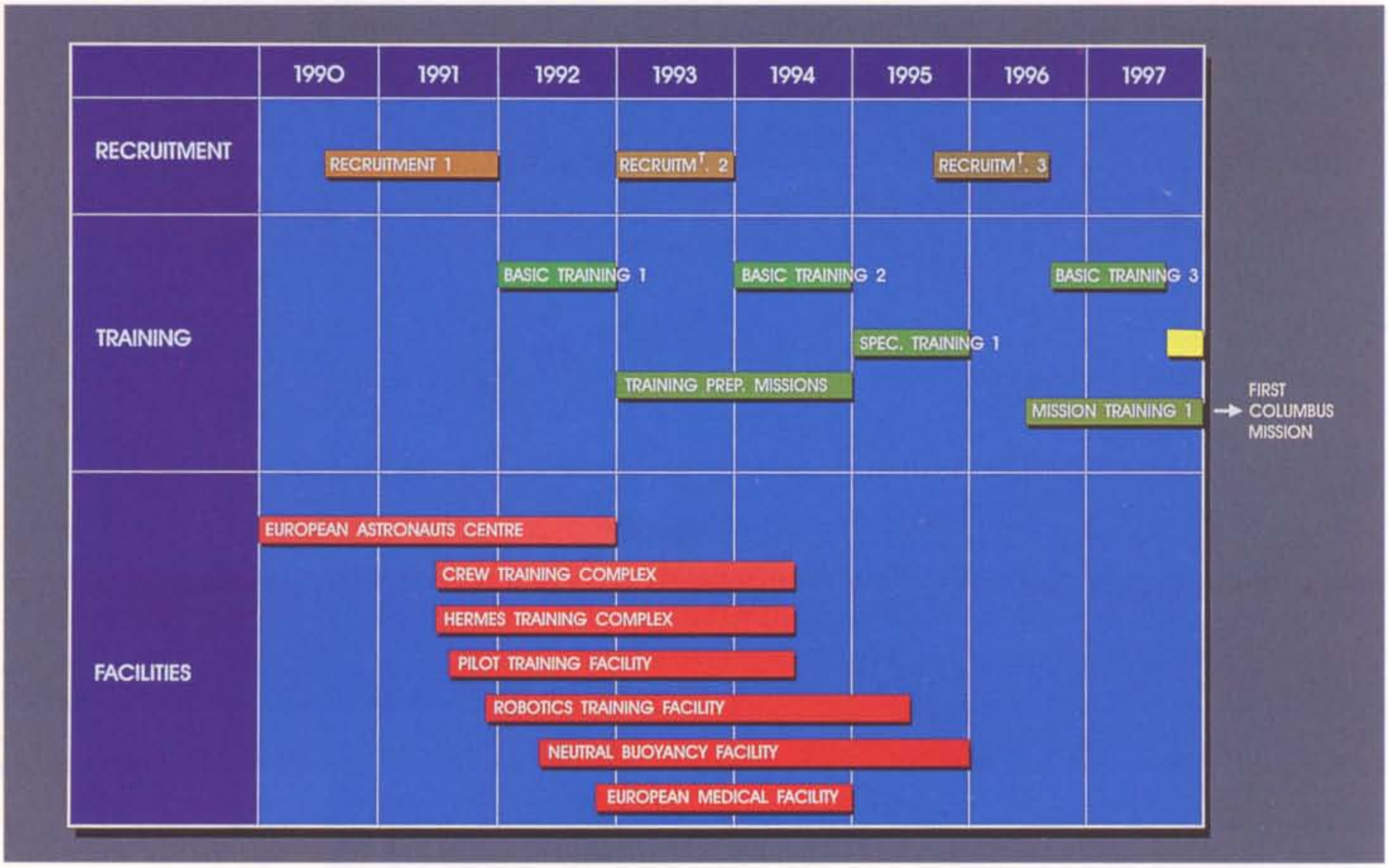


Figure 10. The EAC implementation schedule

(i) their roles in the various phases of the astronaut training cycle (i.e. those needed for basic training have to be ready first)
(ii) the time needed to build up the requisite infrastructure, which in turn depends heavily on the availability of design data from the Hermes and Columbus Development Programmes.

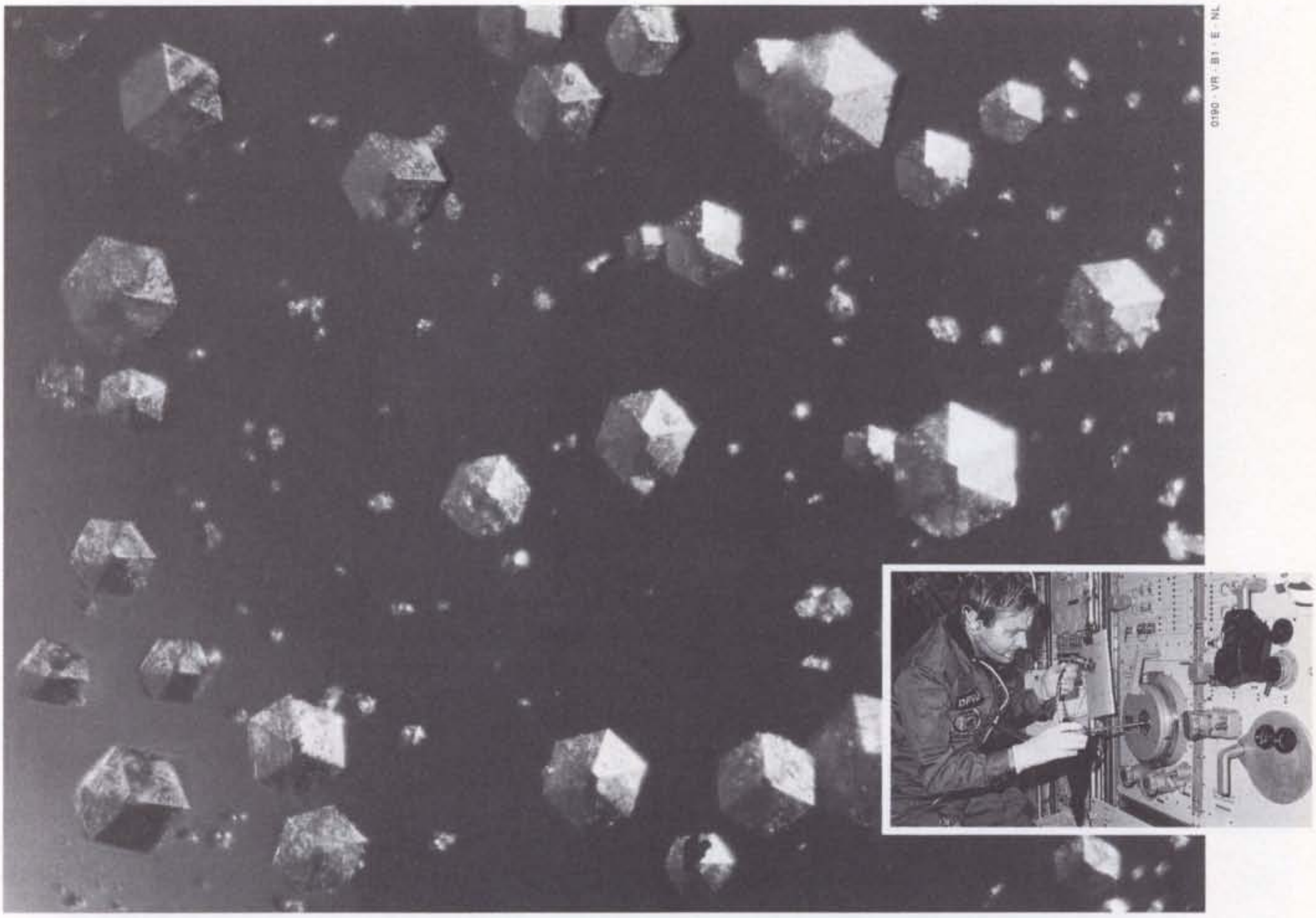
The resulting preliminary schedule is shown in Figure 10.

Conclusion

Now that Europe has decided to go ahead with manned space operations, the necessary infrastructure to support this endeavour has to be built up as quickly and efficiently as possible. Clearly, there will be a transitional phase as the initial infrastructure is adopted to meet the evolving requirements of the user programmes. It is essential, however, to ensure continuity in these activities. The dispersed knowhow gained from the preparatory missions and via national projects has to be collected and safeguarded for long-term utilisation.

This need for a 'centre of knowledge' for Europe's manned space activities was a major factor in both the decision to create and the organisational structure of the European Astronauts Centre.

The mysteries on Earth might well be solved in space.



Without the influence of gravity, some macromolecules, such as proteins, crystallize to near perfection. Scientists have begun to conduct experiments in space laboratories to trace the development of crystals. A better understanding of „space-grown crystals" may well lead to a revolution in the development of pharmaceutical products.
Research in microgravity, for example, must be conducted in laboratories which possess generic qualities similar to the conditions on Earth. Only the results which are comparable with those attained in the terrestrial environment are of significance to the scientific community.

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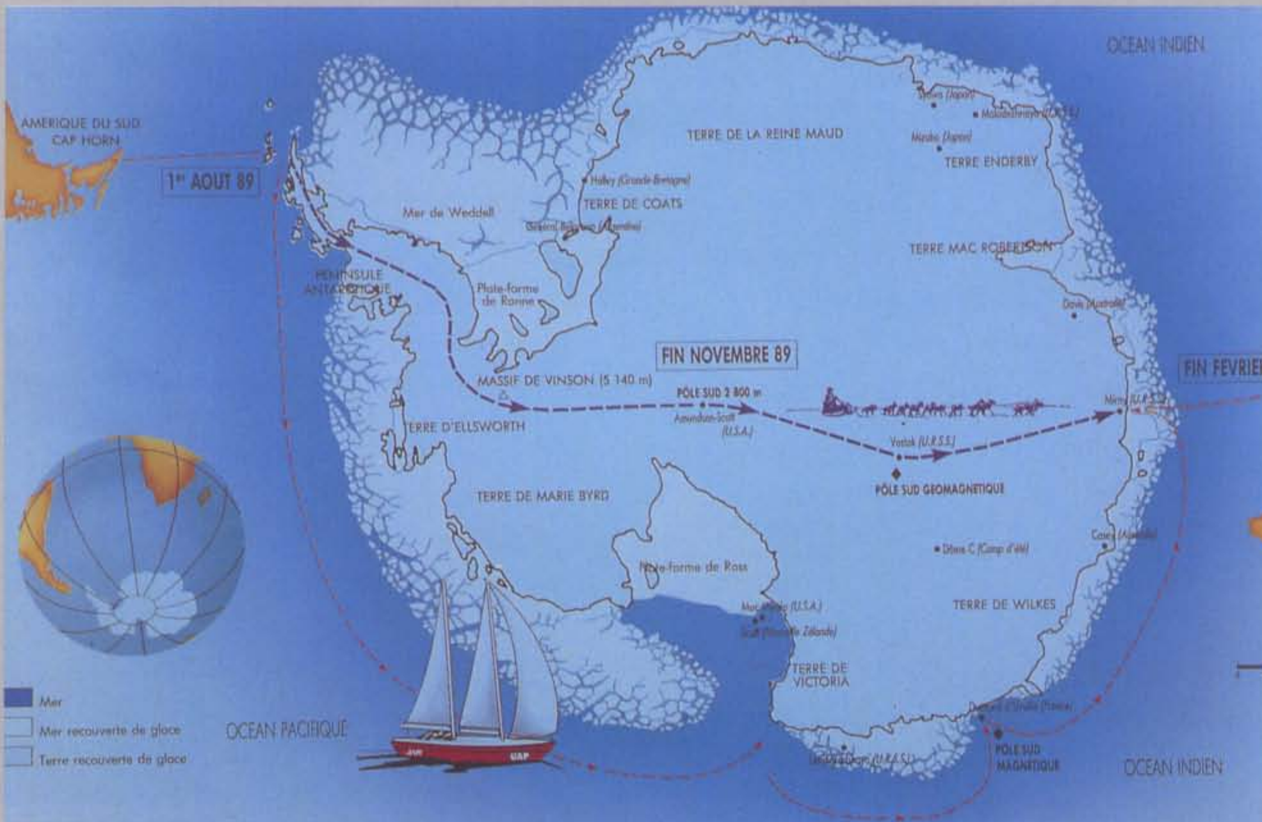

Figure 1. Route taken by the expedition team

Figure 2. The team, from left to right: Keizo Funatsu, Quin Dahe, Will Steger, Jean-Louis Etienne, Victor Boyarsky and Geoff Somers

An Antarctic Crossing as an Analogue for Long-Term Manned Spaceflight

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At its meeting in November 1987 the ESA Council at Ministerial Level decided that Europe should acquire the capability to provide for Man living and working in space. The Ministers noted 'the importance of continuing studies and technological programmes concerning the expansion of the European in-orbit infrastructure to render it fully autonomous'.

The long-duration space missions planned for the end of this century will involve both physiological and psychological problems for the crew who will fly them. If Europe is to achieve autonomy in space, it must increase its expertise in these associated disciplines. One means of acquiring relevant experience is to study human behaviour in environments that are similar from a psychological viewpoint. A planned crossing of the Antarctic by a six-man international team therefore offered ESA a unique opportunity to observe the psychological problems that can occur during an international expedition involving prolonged isolation in a hostile environment.

Achieving autonomy in the field of manned missions is a very long-term objective. Through the Columbus and Hermes programmes, Europe is mastering a large number of essential techniques, including high power generation, teleoperation, rendezvous and docking, re-entry, man-related safety procedures, crew intervention, etc. Nevertheless, a number of aspects of Man's living in space for long periods will not be covered by the current programmes; in the case of Columbus they fall under NASA responsibility, while for Hermes the relatively short duration of the missions considerably alleviates the problems.

This grey area encompasses both physiological and psychological considerations. This is why, in 1988, the Long-Term Programme Office (LTPO) of the Directorate of Space Station and Microgravity established an 'intellectual infrastructure' to collaborate with scientific experts in the field, and to perform exploratory studies on human factors.

The challenges encountered during manned space missions are isolation, a hostile environment, danger, confinement, and the difficulties of a small group living together in close proximity for long periods. Such conditions occur in submarines, polar stations, and deep-sea laboratories. In the framework of its European Manned Space Infrastructure studies, ESA's Long-Term Programme Office has performed investigations in some of these areas, for instance polar stations and deep-dive missions in a hyperbaric chamber.

The Transantarctica Expedition study

The Transantarctica expedition took place from 27 July 1989 to 3 March 1990. It involved crossing the Antarctic (Fig. 1) from the Peninsula to the South Pole, known as the 'Pole of Inaccessibility' (furthest away from all coastlines), to the Vostok Soviet base and on, finally, to the Mirny Soviet base on the other side of the Antarctic. By the time the expedition arrived at Mirny at the beginning of March 1990, the six men had covered 5763 km on skis, a team of dogs pulling the equipment on sledges.

Composition of the team

The expedition team (Fig. 2) comprised: Will Steger (USA), Dr Jean-Louis Etienne (France), Victor Boyarsky (USSR), a specialist on the Antarctic, Quin Dahe, a Chinese glaciologist, Keizo Funatsu from Japan and Geoff Somers from the UK. The team of dogs were looked after by Funatsu, while Somers and Steger were 'mushers', experienced with dogs and sledges.

Three of the team were in the age range 40–45, two 35–39 and one 30–34. Two members were married with one child each, the other four were single. The leadership structure was complex due to the different status of each member ('owner', scientist, musher, official representatives, etc.).

The team agreed to participate as subjects in the experiment under the Helsinki Declaration rules on data collection from humans.

Data collection

Data were collected from five of the men. The sixth member refused any contact with psychologists at the outset. The men were given personality questionnaires, some of which are being considered for use in astronaut selection by both NASA and ESA. These questionnaires are designed to reveal psychological mechanisms believed to be important in establishing how individuals and groups of individuals cope with difficult and hostile environments.

During the crossing each subject was supposed to answer a brief questionnaire once a week. This tested mood, motivation, group cohesion and efficiency, leadership and social functions. Physiological data, i.e. blood and urine samples, were collected at the same time.

Data were collected regularly during the first part of the trip, but no questionnaires were filled out from October to the first half of November. This was the most difficult phase, when the team seemed to have serious doubts about being able to complete the expedition, and the lack of data was symptomatic of their low spirits. As the going got smoother again, data collection and ordinary routines were resumed. Body weight was recorded at the start, at the South Pole and upon arrival at Mirny on the other side of the Antarctic. The crew was interviewed in Australia, after completion of the expedition.

The crossing

The team was transported by air to the Antarctic peninsula at the end of July 1989. They encountered a great many difficulties during the crossing. An accident at the beginning of August ruined one of the sledges and damaged another. On several occasions both men and dogs fell into crevasses, but all were saved. Food had been deposited by plane before the expedition began but, because of extremely difficult snow conditions and poor visibility, two of the depots were never found. Progress was sometimes as slow as ten miles per day and on some days the team were unable to move at all because of the poor visibility.

The team rested first at Patriot Hill on 7 November (spending a week with the media) and for a day at the South Pole, at the Amundsen/Scott US base, on 11 December. Progress was then satisfactory, the team covering an average of 17 to 24 miles per day. On 18 January they arrived at the Vostok Soviet base, where they rested for four days. On 27 January they passed 3400 m above sea level. The temperature was extremely low (−44°C), wind conditions were difficult and visibility poor. Going downhill they again encountered crevasses. In the last two days one man was lost for more than 10 hours, managing to survive an entire night buried in snow.

Conditions

The expedition encountered extreme weather conditions, more extreme than they had allowed for, weeks of fog, 'whiteouts' (due to wind blowing the snow), very strong winds (up to 35 m/s) and temperatures often below −40°C. Under such circumstances the loss of a tent could have meant instant loss of life. The snow was often packed in frozen waves (like sanddunes), known as 'sastrugi', which can be difficult to negotiate with skis and sledges. The lost food caches had not been equipped with radio beacons, since they had been so clearly marked that the team had not expected to have any difficulty in finding them.

Rescue

Evacuation by air was possible, but the team learned from experience that it could take up to six weeks to organise air transport. They stated that 'we were not allowed to die', but their confidence in this was clearly reduced during parts of the trip.

Communication

Communication within the group was impaired by language difficulties, workload, wind and fog. Contact with 'mission control' was impaired by radio blackouts for long periods of the expedition. However, this type of expedition in principle requires little from mission control except security, backup and extra supplies. Communication with families at intervals was as free and uncensored as it can be over radio networks.

Communication with the media clearly interfered with the expedition, sometimes positively, sometimes negatively, and it had varying effects on the individuals.

Performance
In total, the team crossed 6400 km on skis and dog sledges — the longest (amateur) sledge trip on record. In addition to this record-breaking performance, it is particularly interesting from ESA's point-of-view that an international crew of six men were able to stay together for more than seven months, under extreme conditions, perform well, and return without apparent serious conflicts or problems. The team also demonstrated an ability to handle the pressure of media attention with grace and style.

Figure 3. A day like any other

Results from the questionnaires and interviews
The team was composed of mentally healthy and resourceful individuals; there are no pathological or grossly abnormal recordings. However, there is still some variance that might turn out to be interesting for further work on the selection of space travellers. For reasons of confidentiality, particularly in view of the small number of subjects, the following part of the report may appear incomplete. Again, because of the size of the group, statistical analysis was largely inappropriate.

Cultural differences and language problems also created some difficulties with the data. Only two participants had English as their mother tongue. One subject refused to fill in a questionnaire until the end of November, but from then on he participated loyally in the data collection.

Defence
The psychological defence mechanisms were evaluated by questionnaires completed before the crossing. Results were compared with published material and interviews with the expedition members, in particular the post-expedition interviews in Australia.

The defence mechanism preferred by each expedition member varied. As expected, there was a liberal use of intellectualisation as a defence mechanism, particularly amongst the scientists in the team. This is regarded as an adequate mechanism, which did not interfere with their ability to solve problems. However, there was also a tendency to use denial, which is a more primitive mechanism, and in some cases may be related to inadequate performance in dangerous situations. The tendency to use denial may apply to those team members who seemed to have had more problems than the others, without their admitting so in any written report.

The use of intellectualisation and compensation was quite clear in many of the reports from team members to home base, and to journalists. Poor communication was considered rather unimportant — one 'tends to communicate too much in real life' anyway. The fear of being left without any support for as long as up to six weeks was handled by statements such as 'we were not allowed to die'. On the other hand, the feeling of several participants of being close to Scott and his fate is remarkable, as are their thoughts on the generally held position that the reason for Scott's fame is that he died: 'only the dead become heroes.'

Finally, reluctance to answer the questionnaires, since it raised the possibility of failure ('Are you going to make it?') is an interesting case of repression, which may be an inadequate defence mechanism.

Personality
The group was too small for statistical treatment of this material to be valid. However, there are interesting suggestions of relationships between the personality scales and performance variables. We also believe that there may be a correlation between the personality tests and who was preferred for emotional support during the crossing. This seems to tally with the general findings and conclusions of previous research on the predictive power of such tests for performance in small groups under pressure.

There may also be a relationship between the personality scores and the managerial style and organisational problems within the group. It is difficult to expand on this without breaking confidentiality, but there seems to be reason to use these scales in further studies.

Selfscores during the expedition

As mentioned earlier, the self-report questionnaires were not completed for two months, from the end of September to the end of November. This was an interesting period, and the lack of performance of this task signalled that something was going wrong.

One team member objected strongly to the questions from time to time but filled them out loyally at other times. The lack of response and the issues he protested about were related to problems with the organisation of the expedition. This may have been due to exhaustion, fatigue or depression in the group.

One team member filled in the questionnaires with the same number most of the time, and these answers have been excluded. Cultural differences and language difficulties are possible reasons. However, at other times he filled in almost all questions with reasonable numbers. These have been accepted, since the responses given at these times were reasonably consistent.

Figure 4 shows the profile of the 'mood'. This is a score constructed from answers to the questions: 'Do you feel tired? Are you happy that you came along? Do you feel anxious? Are you worried? Have you been angry during the last 24 hours? Do you feel well?'

The initial scores were very high. There was a peak of mood just before reaching the South Pole (8 December: 110 km left to the Pole, good snow conditions, good progress). After the visit to the Pole the mood scores dropped slowly but systematically. The all-time low occurred around a shift in schedule. The going was uphill, cold, there were 'whiteouts' and 'sastrugi', radio contact was difficult and the altitude was very high. Some concern also surfaced in the reports regarding crevasses on the last stretch down to Mirny, in particular combined with 'whiteout' problems. The mood rose again after reaching Vostok, with the warm reception there and the logistic support offered by the Soviets for the last stretch of the operation.

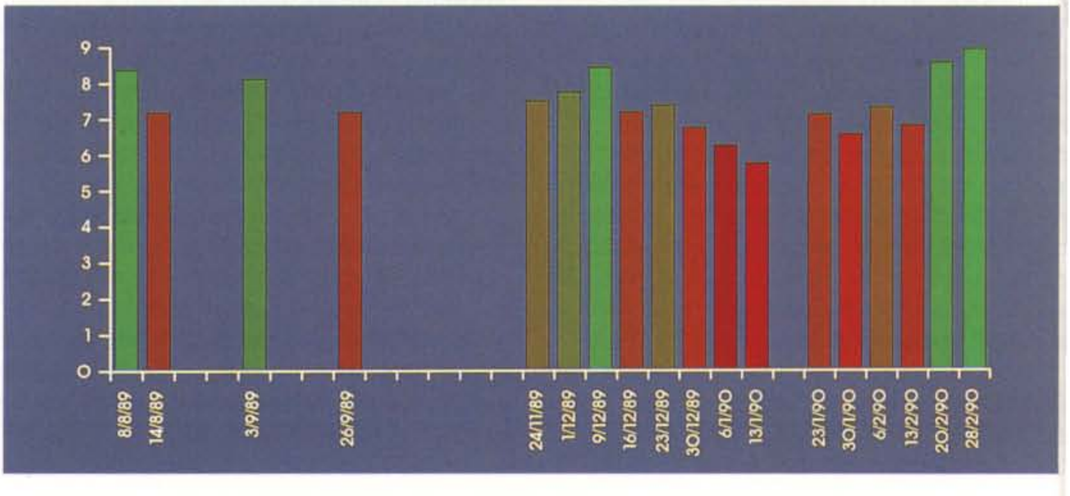

Figure 4. Profile of the team's psychological 'mood' during the expedition

This tallying with external events supports the validity of the subjective mood reports and the usefulness of such questionnaires for monitoring mood. It remains to be seen whether this also affects the physiological indicators that were monitored, but this information is still under review.

Lessons for space travellers

The most relevant conclusion for ESA is that it is possible for six men from different nations, and different cultures, to complete an expedition of more than seven months' duration through a very hostile and isolated environment. Not only were they able to accomplish the task, but they seemed to function very well as a group, and this continued after the trip.

The team had not been picked in the systematic way that space travellers will be chosen. The personality range evident in the tests may be wider than that accepted in astronaut selection. The scientists in this group fared very well and seemed to have resources which made it easier for them to handle the media pressure during and after the crossing, but media pressure is clearly a strong stress factor. The key selection criteria are not professional skills or knowledge and recruitment must not be based on selecting the best purely on these terms. Once the minimum requirements in terms of skills and physical fitness are satisfied, selection must be based on personality and social skills.

Meticulous planning was a clear antistress factor for the team; confidence in their ability to achieve their aim was a function of their confidence in their own meticulous planning. Training provided a test of the efficiency of the methods to be used and the composition of the group. Several team members ascribed at least some of their success to the training trip they made in Greenland the previous year.

The international aspects of the expedition were strongly emphasised. It is perhaps surprising that many of the expedition members found that they felt very strongly that they were representing their own nation. In group interactions this became an important factor; during disagreements they felt they had to make it clear that if they were criticised it should be as individuals, not as representatives of one particular nation.

Dissimilarities

The organisation of each day was greatly affected by the very heavy physical workload, which was the same for everyone and kept them united. Skiing and dog-sledging for 20—30 miles per day required total concentration and maximum effort from the whole team, including the dogs. The relationship between men and dogs was also peculiar to this expedition and it seems obvious that some emotional needs were met by the close contact between man and dog. This was much more than just having a pet around; the work of the dogs was vital to their progress and this common purpose linked men and animals together in an particular way.

The goal for each activity and the feedback in terms of performance (mileage) were very clear to everyone. These are positive factors for group interaction and coherence which may not exist to the same extent, or at least not so clearly, in a space situation. The success of this group must be evaluated against these important variables.

Conclusion

Such studies may provide important information on how small groups perform in long-lasting and challenging situations, relevant for the composition and structure of groups to endure long-duration space travel. It may yield information valuable for astronaut selection and training. It also gives a model for communication between the expedition and 'mission control' and communication with family and with the media.

Interaction with the environment and the type of task produces an irrelevant data set. This may be controlled by comparing small groups in many different types of setting. The physical and physiological part of the variance must be measured. The psychological tests used must be standardised, and should be relevant to tests used in the selection of astronauts and/or in the final composition of crews.

Europe has greatly increased its ambitions in space: sending Man into space is a formidable responsibility. Preparation for this endeavour is not just a question of technology but necessitates mastery of a number of other, non-technological, disciplines. The study of space-related human factors is totally new to ESA and analogous situations offer excellent opportunities to learn about this new discipline. In this respect the Antarctica can be considered as a pioneering area.

Giotto's Reactivation and Earth Swing-by

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Two 'space firsts' have been achieved this year with ESA's cometary spacecraft 'Giotto', which explored Comet Halley in March 1986. After 1419 days of hibernation out of ground contact, communications were re-established and the spacecraft re-activated. Eighteen weeks later, Giotto returned from deep space to make an Earth-gravity-assist swing-by to boost the spacecraft onto a course for an encounter with another comet, Grigg-Skjellerup.

Introduction

On the night of 13/14 March 1986, Giotto flew past the sunlit side of Comet Halley, at a distance at closest approach of 596±2 km, with a relative speed of 68 km/s, and provided a wealth of scientific data, including spectacular images of the active cometary nucleus. Even before this successful event, ideas for a second encounter were already being put forward. The survival of the spacecraft, albeit somewhat battered by hyper-velocity dust impacts, and the thrifty navigation since launch – less than 10% of the initial hydrazine fuel load had been consumed – gave further impetus to what has subsequently evolved into the 'Giotto Extended Mission' (GEM).

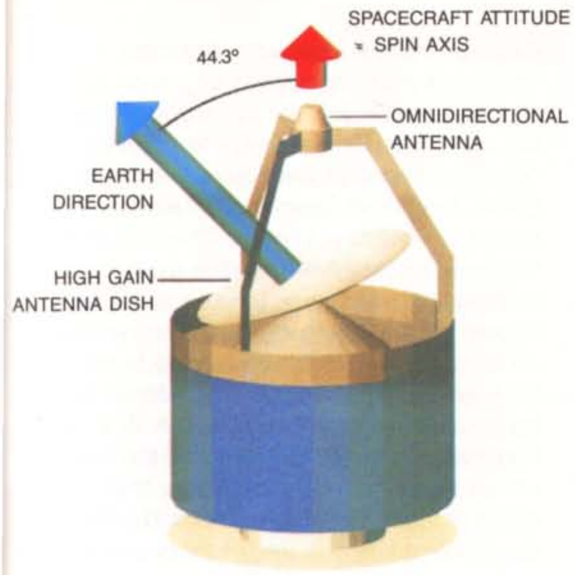
The post-Halley strategy that kept most options open was identified as an orbit transfer back to Earth. Depending upon the Earth swing-by conditions, one of a number of possible targets, either another comet or an asteroid, could be reached. Between 19 and 21 March 1986, a series of large orbit manoeuvres was performed which consumed more than half of the remaining hydrazine. The resulting orbit period of close to ten months meant that the spacecraft would make six complete revolutions around the Sun in the same time as the Earth made five, and five years after launch, to the day, on 2 July 1990, Giotto would return to the close vicinity of the Earth.

Hibernation

Operating Giotto during several years of interplanetary cruise would have been prohibitively expensive and it was therefore decided to put the spacecraft into hibernation. An attitude had to be chosen for which temperature fluctuations, caused by the changing distance from the Sun and the natural variation in solar aspect angle (the angle between the spacecraft's spin-axis and the spacecraft-to-Sun direction), were limited as much as possible. The optimum orientation of the spin-axis was almost perpendicular to the plane of the Earth's orbit around the Sun, known as 'the ecliptic' (Figs. 1 & 2).

For normal communications at large distances, Giotto's despun High-Gain Antenna (HGA), the radio boresight of which is inclined by 44.3° to the spacecraft's spin-axis, must point to within 1° of the Earth's direction. From shortly after the start of the manoeuvre into the hibernation attitude, executed on 2 April 1986, and for the whole of the hibernation period, despite the continuous change in the spacecraft–Earth direction, the HGA would never again naturally point towards the Earth. Thus, contact with the spacecraft was lost and eventual re-establishment of communications would be a complex process.

During the intervening years, planning for the Giotto Extended Mission gradually began to take shape. The ESA Science Programme Committee approved the first phase of the extended mission – the reactivation and subsequent check-out of the scientific experiments. Comet Grigg-Skjellerup was chosen as the next target, being the best compromise between scientific interest and operational feasibility. In 1989, detailed preparations were made and a maximum of 35 days was allocated for re-activating the spacecraft.



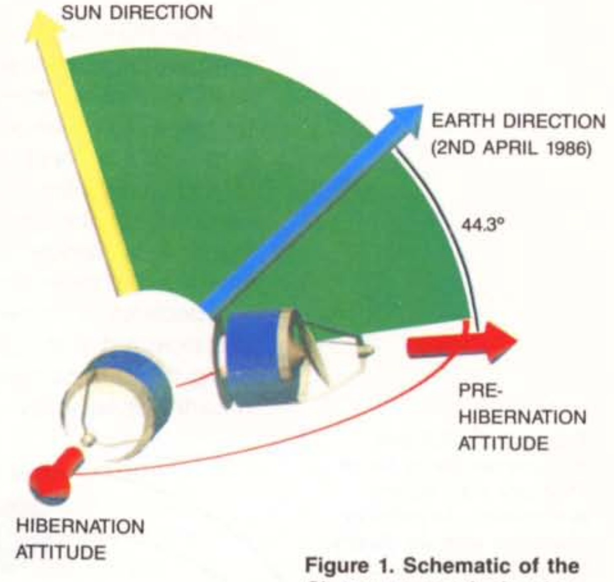


Figure 1. Schematic of the Giotto spacecraft showing the omni-directional Low-Gain Antenna (LGA) and the despun High-Gain Antenna (HGA)

Figure 2. Hibernation attitude manoeuvre

Re-activation strategy

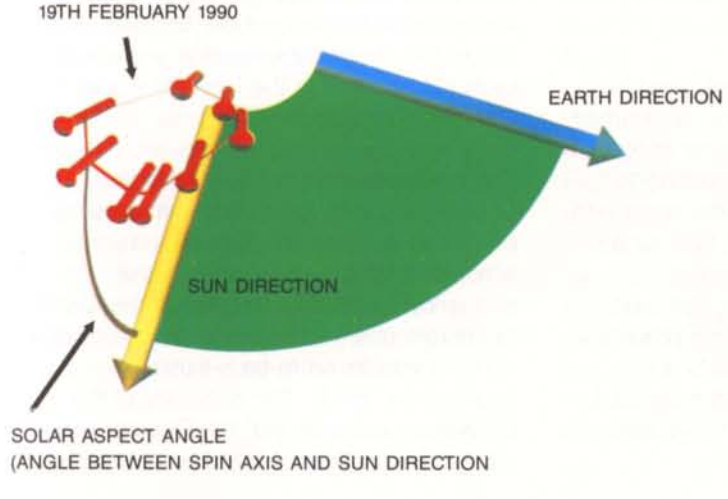
Initial communications with Giotto would have to be made through its small omni-directional Low-Gain Antenna (LGA). Link-budget calculations showed that commands could be decoded only if the transmitter signal was very strong, and just to detect a signal back from the spacecraft would require a very large ground antenna. The only system powerful enough was the 70 m antennas and 100 kW transmitters of the NASA Deep-Space Network (DSN) and it was generously made available for the GEM. The strength of the signal received on the ground was expected to be insufficient to allow decoding of the telemetry and operations would have to be continued 'in the blind' until the spacecraft could be manoeuvred to point the HGA towards Earth.

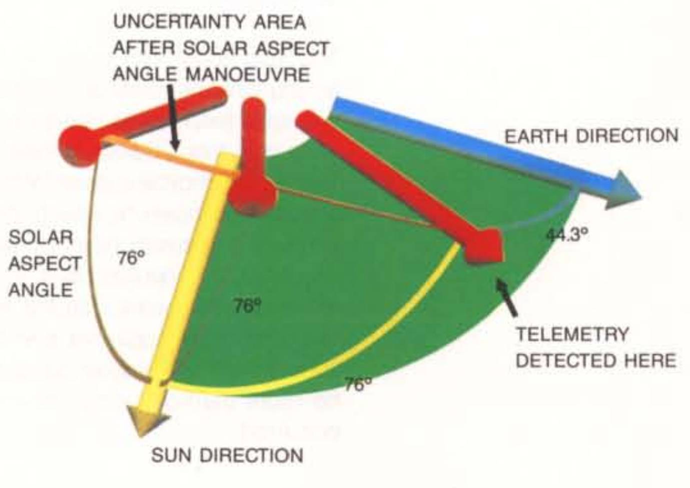
The hibernation attitude achieved was not known precisely and could only be estimated based on an assumed thruster-system performance. Variations in performance can cause a dispersion of up to 10% in manoeuvre length and up to 1–2° in manoeuvre direction. In addition, during the hibernation period, the spacecraft's attitude was perturbed by minute torques caused by solar radiation pressure, and changed continuously in a direction perpendicular to the instantaneous Sun direction. Over the several years of hibernation, the change in spin-axis direction followed a spiral pattern. While the shape of this pattern was well known, its amplitude could not be estimated with good accuracy. By the start of 1990, therefore, there was a rather large 'uncertainty domain' within which the attitude was expected to lie (Fig. 3).

The basic idea of the re-activation strategy was to make use of the spacecraft's on-board capabilities to control the spin-rate at 15 rpm and to make a manoeuvre to a specific (date-dependent) solar aspect angle with no change in Earth aspect angle (the angle between the spin-axis and the spacecraft-to-Earth direction). This would then reduce the uncertainty in the attitude to a point on an arc of a small circle (Fig. 4).

Figure 3. Attitude uncertainty area before reactivation

Figure 4. Reactivation manoeuvres to point the HGA towards the Earth





With the HGA connected to the on-board transmitter, a second manoeuvre would then be initiated to reduce the Earth aspect angle. Nominally, the solar aspect angle would remain constant and, at some point during the manoeuvre, the HGA boresight would sweep across the Earth, providing a down-link for a few minutes. Immediately, the manoeuvre disable command would be sent but, because of propagation delay, the signal was expected to be lost. The spacecraft would then be manoeuvred back in 4° steps in Earth aspect angle.

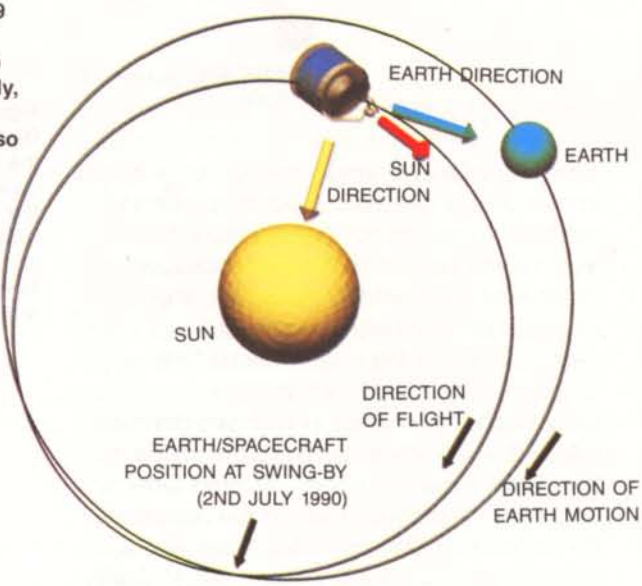


Figure 5. Orbital and attitude geometry on 19 February 1990 before reactivation. In order to show the attitude clearly, the view is from below (south of) the ecliptic, so that the orbital motion appears clockwise, in contrast to the more normal view from above the ecliptic, as in Figure 9

If no signal were detected, the reverse Earth-aspect-angle change manoeuvre would be commanded with the HGA connected to the redundant transmitter. This sequence of manoeuvres was christened 'a cycle'. The first, cycle zero, would be performed with a partially unknown spacecraft configuration, in that autonomous switching of units could have occurred during hibernation. An unsuccessful first cycle could be caused by non-execution of a manoeuvre due to failure of a unit in the command chain, or an error in the telemetry chain, for example the HGA not despun.

The spacecraft was originally designed for an eight-month mission. After four and a half years in deep space, failure of one or more units was more than a remote possibility. Twelve more cycles were foreseen, each with a similar manoeuvre sequence, but using different combinations of prime and redundant spacecraft units. The plan was to systematically exclude the more probable failure scenarios, so that eventually a successful re-activation could be assured if no more than one single-point failure had occurred.

Contact via the Low-Gain Antenna

The re-activation operations began on 19 February 1990, when the spacecraft was still more than 100 million km from Earth (Fig. 5). Using orbit predictions provided by ESOC, the NASA Deep-Space Network station in Madrid pointed its 70 m antenna in Giotto's direction. After sending the blind commands to configure the spacecraft for S-band frequency down-link communication, an on-board transmitter connected to the LGA was commanded on. Immediately after the round-trip signal time of 11 min 27 s had elapsed, the station detected the weak carrier signal from the spacecraft. This confirmed that Giotto was alive and within a few thousandths of a degree of its predicted position, but how healthy?

Contrary to popular belief, this initial success after only 2 h of operations was merely the easy (relatively speaking) first stage of the re-activation. As expected, the signal strength was far below the threshold for telemetry modulation, although the ground-station receiver was able to lock onto the carrier signal. This meant that good-quality Doppler data were obtained, and their detailed analysis was to provide extremely useful information on the kinematics and dynamics of the spacecraft. This in turn meant that over the next few days the control team were going to be 'partially-sighted' and not, as had originally been presumed, 'totally blind'.

Doppler data

The frequency shift between the transmitted and received carrier signal, caused by the Doppler effect on both the up- and down-link legs, is directly related to the spacecraft's radial velocity relative to the tracking station, a quantity commonly called 'range-rate'. In practice, mean values of range-rate are derived over contiguous, equal time intervals. For orbit-determination purposes, the so-called 'count times' are chosen to be in the range 1–10 min or more because, the longer the interval, the more any noise or cyclic component in the Doppler signal is attenuated or smoothed out.

The difference between the measured Doppler and that computed from an orbit prediction is called the 'Doppler residual', which can be expressed in terms of frequency or velocity. At reactivation, Giotto's range-rate was −14.5 km/s and the Doppler residual was found to be −1 m/s or, equivalently, 15 Hz. The accuracy of the prediction was such that the Doppler residual changed only slowly with time. The attitude manoeuvres, though, would cause a small change in the range-rate and lead to an abrupt change in the Doppler residual. Monitoring of the Doppler residual could therefore provide an immediate indication of a manoeuvre taking place.

Dust impacts at Comet-Halley encounter had resulted in some loss of spacecraft mass and Giotto's spin axis no longer coincided with its physical longitudinal axis. In particular, the LGA radio centre was then offset from the spin-axis and rotating around it with a velocity of 30 mm/s. At reactivation, this magnitude was not known, but it was appreciated that the motion of the LGA would give rise to a sinusoidal modulation on the raw Doppler. So that the phenomenon could be well observed in the processed Doppler, short count intervals of 10 s were required. Because of the averaging effect, the short-term signature in the Doppler appeared periodic, but in a complicated form.

Within hours of reception of the first signal, navigation experts at NASA/JPL, using a technique known as Fourier analysis, managed to decode the information hidden in the Doppler data and derived the spacecraft's spin rate. The same facilities were not available at ESOC, but the necessary software was written within two days and a spin rate of 15.31 ±0.01 rpm was confirmed. This was 0.24 rpm higher than expected.

Unsuccessful manoeuvre attempts
On 20 February, the HGA was connected to the on-board transmitter and the manoeuvre commands for cycle zero sent. For several hours, no signal was received. Eventually, the transmitter was switched back to the LGA. There had been no significant change in the Doppler residual and the nature of the short-count-time Doppler signal was identical to the previous day. It was virtually certain that no manoeuvre had taken place.

Tests on the same day proved that both spacecraft transmitters were operational, and so the number of operations for each cycle could be cut by half. It was decided to deviate from the strategy and continue making manoeuvre attempts using the LGA. DSN station personnel were requested to provide real-time readings of the Doppler frequency residual during the attempts.

The next day, cycle 1 was tried and again nothing happened.. The HGA despin mechanism was commanded on and off. Calculations based on the principle of conservation of momentum showed that the spin rate should be 0.1 rpm higher when the despin was on. That the Doppler analysis showed no change caused much concern, because failure of the despin mechanism would automatically mean termination of the mission.

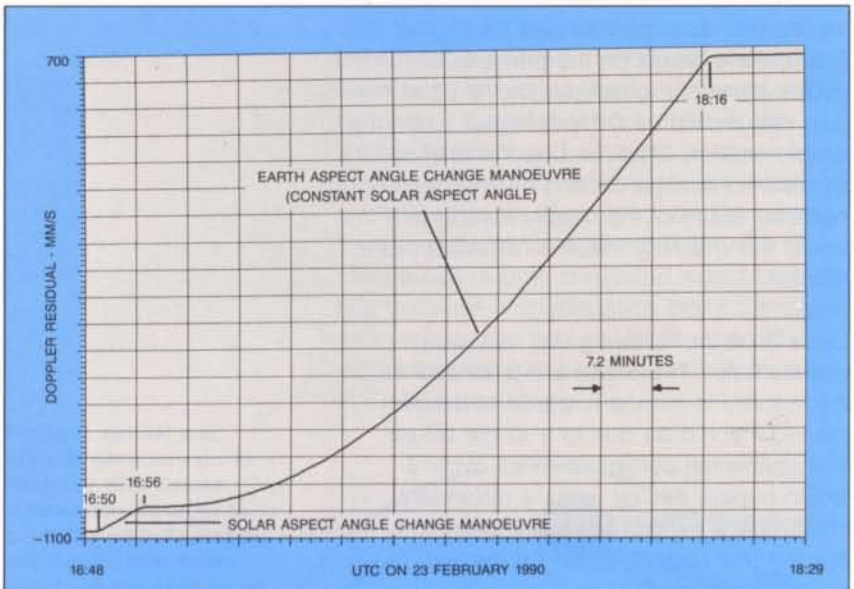
Cycle 2 on the following day was also unsuccessful. There was a possibility that the inability to manoeuvre and to despin the HGA could be due to a single failure. The spacecraft configuration for cycle 3 would bypass this by using a redundant chain. Many experts were already of the opinion that cycle 3 would be the last realistic chance.

Meanwhile, a method had been developed for rapidly determining if the HGA despin mechanism responded to a switch-on command. The period of the beating, evident in the 1 min count-time Doppler residual, should change from 3.2 to 2.4 min.

Telemetry acquisition
On the afternoon of 23 February, the commands were sent to switch on the HGA despin and, half an hour later, to manoeuvre the spacecraft. The first Doppler residual reading after 4 min indicated a change. Four minutes later there was no doubt, Giotto was moving. Then the residuals remained constant for a while. It was realised that this did not mean the end of the manoeuvre. Rather, the velocity increment at the start of the Earth-aspect-angle change was perpendicular to the Earth's direction and did not change the Doppler (Fig. 6a).

As the manoeuvre was in progress, a plot of the earlier Doppler residuals was sent by the DSN to ESOC. The period in the signal had changed exactly as predicted (Fig. 6b). A working spacecraft configuration had been found!

From the variation in the Doppler residual during the course of the manoeuvre, the Flight-Dynamics Team was able to reconstruct with fair accuracy both the start and end attitudes. The next day, the HGA was connected to the transmitter and the Earth-aspect-angle manoeuvre performed. As expected, the antenna beam swept across the Earth and overshot before the manoeuvre-off command reached the spacecraft.



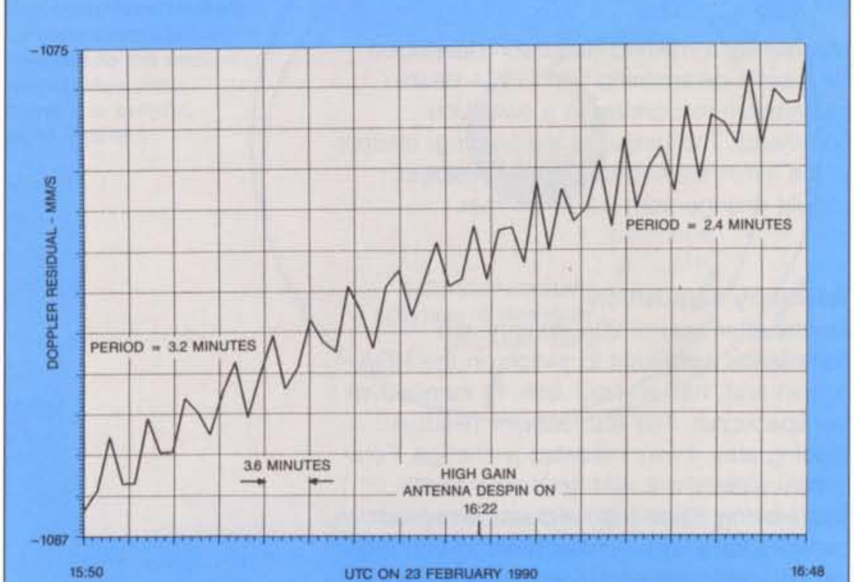


Figure 6a. The first reactivation manoeuvre as seen from the residuals of the 60 s count-time Doppler data obtained at the Madrid DSN station

Figure 6b. Successful switch-on of the HGA despin mechanism indicated by the change in beat period in the Doppler residuals

After three return steps of 4°, the HGA was Earth-pointing and continuous telemetry was received in Madrid (Fig. 7). Due to an on-board anomaly, on reception at ESOC all the data was flagged as 'bad quality'. Then suddenly, after 1 h, telemetry abruptly ceased. It took more than another day to discover that a component in the Data-Handling Subsystem had failed (probably due to very high temperatures) and to solve the problem by switching to the back-up unit.

After 150 h of intensive operations and analysis, Giotto was officially declared to be 're-activated'.

Orbit and attitude control

Following reactivation, Giotto's orbit was determined from range and Doppler tracking data. The results showed that at a distance of 100 million km from Earth, the spacecraft was only 40 000 km away from its predicted position, and its heliocentric velocity of 37.4 km/s was just 13 m/s different from the expected value.

The small modification to the orbit needed to set the spacecraft onto the Earth-intercept trajectory was performed in two steps. On 12 March, a radial thruster firing in pulsed mode for 2.6 h provided a velocity increment (delta-V) of 7.1 m/s. One week later, a continuous burn of a lower axial thruster for 1 h gave another delta-V of 3.7 m/s (Fig. 8).

The orbit control was complicated by the frequent precession manoeuvres needed to change the orientation of the spacecraft in order to maintain the HGA Earth-pointing and to satisfy the constraints on the solar aspect angle. The angle's value had to follow a narrow corridor dictated by thermal and power considerations. In the spring, when the spacecraft was closest to the Sun, priority was given to keeping vital spacecraft units as cool as possible (at the expense of very hot experiments, thus delaying their check-out). Later, it became more important to maximise the power output from the solar cells and to keep the spacecraft warm enough.

In all, 18 precession manoeuvres changed the orbital velocity slightly. Although the planning foresaw their effects on the trajectory, there were inevitable changes in the scheduling of the manoeuvres and variations in their actual performance. Also, as the Earth swing-by time approached, the predictions of spacecraft position in the vicinity of the Earth changed, but also became more accurate. Consequently, it was necessary to make two smaller orbit

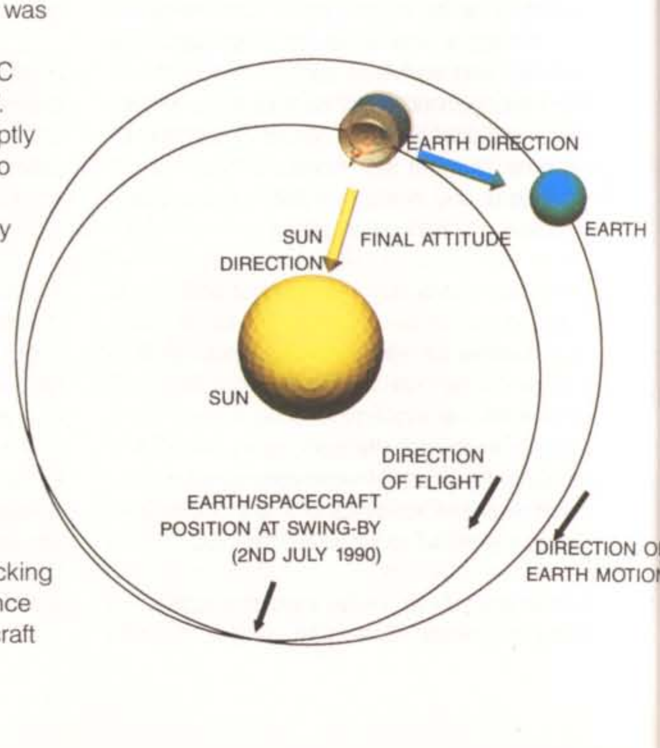


Figure 7. Orbital and attitude geometry after reactivation

trims, both radial-pulsed manoeuvres, on 31 May and 12 June.

On 16 June, the spacecraft spin-axis was slewed through 63° so that, for the whole of the swing-by period until 7 July, communications and tracking could be performed via the LGA. This strategy avoided the need for making any further orbit-perturbing attitude manoeuvres before the swing-by. The spacecraft attitude was carefully chosen to minimise the duration of the one unavoidable communications outage that would occur shortly after the closest approach to the Earth, when for a few hours the spacecraft's body would shield the LGA from the line-of-sight of a ground station.

Unfortunately, the signal strength when using either the 15 m antenna at the ESA station in Perth, Australia, or the 30 m antenna of the DLR station at Weilheim in Bavaria, in conjunction with the LGA, is too weak to guarantee reception of usable tracking data when the distance to the spacecraft exceeds about 1 million km. This meant that, until 29 June, reliance had to be placed on the NASA DSN. In late June, the network was heavily committed to many other projects and only four passes using the 34 m antenna at Madrid were available for providing tracking data to refine the orbit determination.

Giotto's attitude is determined from a combination of Sun-sensor and star-mapper data. Because Comet Halley's dust punctured the star-mapper baffle, the instrument can be used only during the part of each revolution when it lies on the shadowed side of the spacecraft. This limits the number of available bright stars that can be sensed, but the planets can also serve as 'targets'. Indeed, for the previous weeks, the Earth had been the primary reference object. In the swing-by attitude, neither the Earth nor any star appeared in the field of view. Only after an anxious wait of eight days did the Moon move sufficiently to be detected, so that the swing-by attitude could be confirmed.

The Earth-gravity-assist principle

For it to be able to reach Comet Grigg-Skjellerup, the orbital energy of Giotto had to be increased substantially. Its orbit inside that of the Earth's around the Sun had to be raised to one outside, with a period of about 13.5 months (Fig. 9). Achieving this with a conventional manoeuvre would have needed more than fifty times the amount of fuel remaining on-board. The only possibility was to exploit the Earth's gravity.

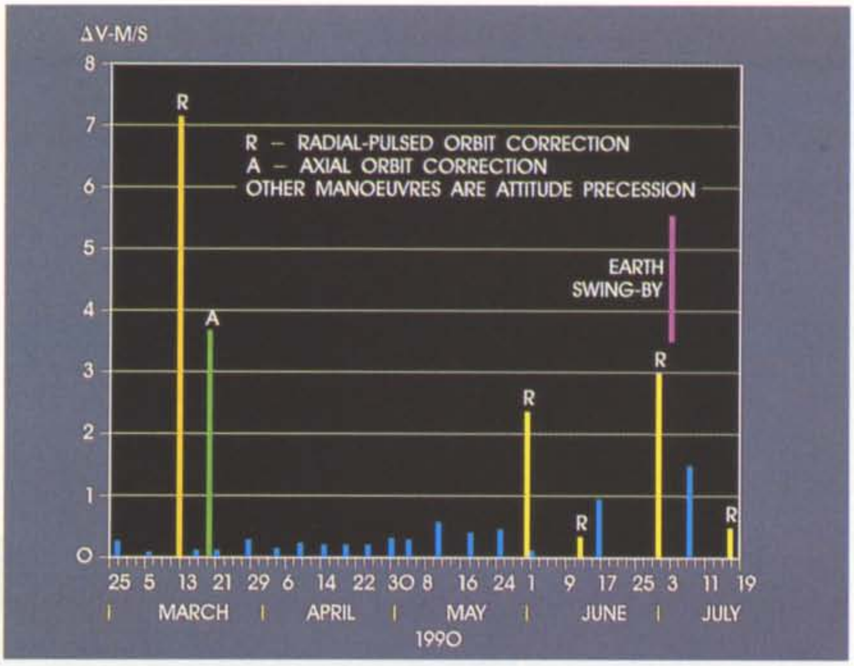


Figure 8. Giotto manoeuvres

In the vicinity of the Earth, the spacecraft's trajectory would be a hyperbola. The orbit design called for a distance at closest approach (perigee) of about 29 100 km from the Earth's centre, or 22 730 km above the Earth's surface, at which point Giotto would attain its highest geocentric velocity of

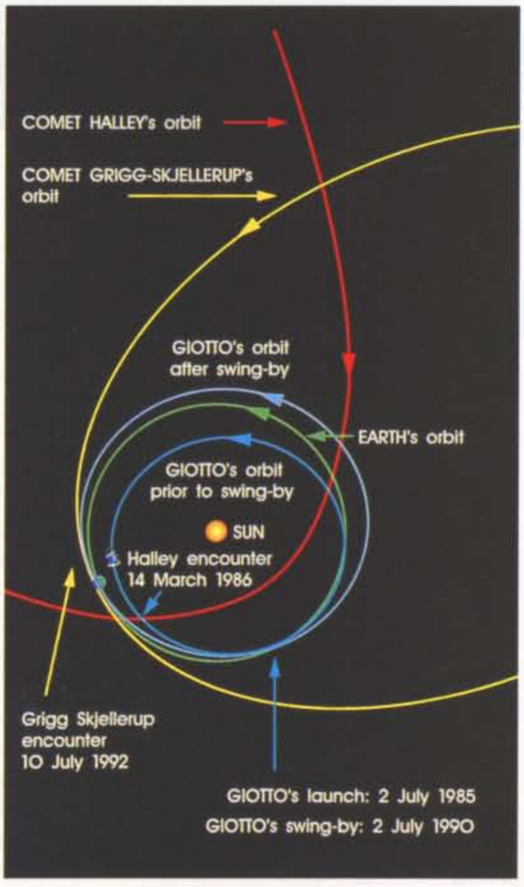


Figure 9. The orbits of the Earth, Giotto and Comets Halley and Grigg-Skjellerup

6.3 km/s (Fig. 10). The plane of the hyperbola was to be inclined by 45° to the equator, and the spacecraft would cross the equator just 3000 km above the altitude of geostationary satellites.

Far away from the Earth, the trajectory approaches an asymptote and there the spacecraft's geocentric velocity is known as the 'hyperbolic excess velocity'. The magnitude of this velocity, 3.5 km/s for Giotto, is identical on the incoming and outgoing legs, so that the swing-by merely causes a change in the direction of the geocentric velocity and not in its magnitude. However, the cross at the centre of ellipse number 1 in Figure 11 was the then best estimate for the prediction of the position that Giotto would reach in the target plane (chosen for ease of explanation here as the plane normal to the geocentric velocity at perigee). The uncertainty in the estimate was such that the actual position would, with 99% probability, lie within the boundary of the ellipse.

At that time the preliminary target point was computed. Since the target was situated well outside ellipse 1, it was clear that one more orbit correction manoeuvre would be necessary.

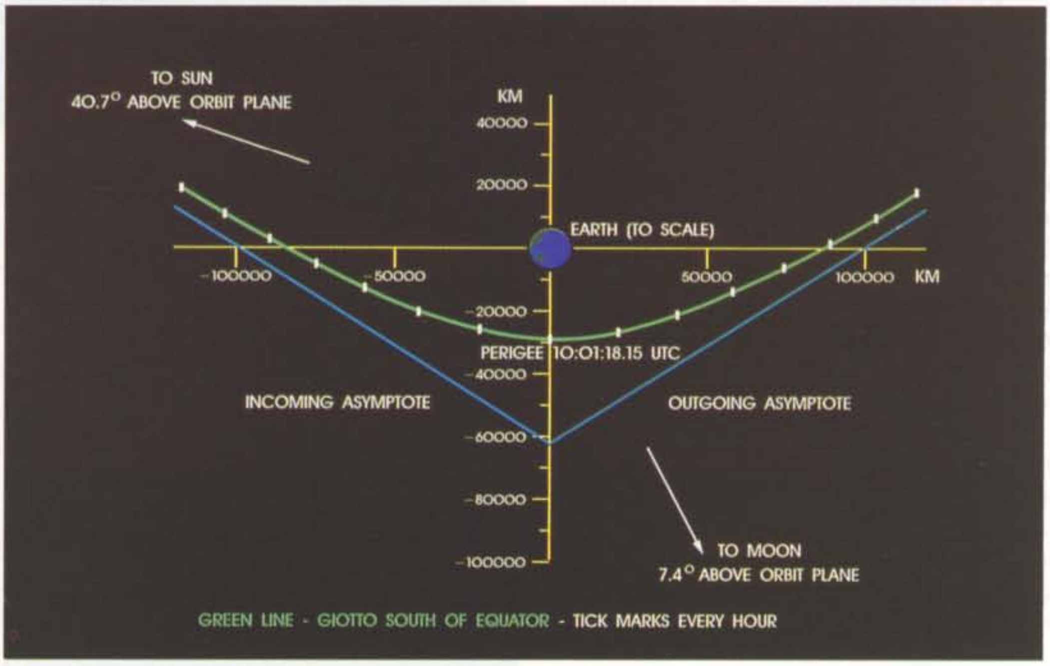


Figure 10. Giotto's hyperbolic trajectory at Earth swing-by

the bending of Giotto's geocentric trajectory through 64° would cause an increase in its heliocentric velocity of 3.1 km/s. The price to be paid for this energy boost would be a reduction in the Earth's velocity around the Sun of the order of 1 mm in every million centuries!

The magnitude and direction of the incoming hyperbolic excess velocity could be changed only by an insignificant amount by means of an orbit manoeuvre. To ensure the correct deflection of the trajectory in the desired direction, the position of the spacecraft relative to the Earth at perigee had to be controlled to great accuracy. Any error would have to be corrected after the swing-by and only a fraction of the on-board thrust capability of 60 m/s was available for this purpose.

Final targetting

Using tracking data obtained up to 20 June, With the accumulation of more tracking data, and as the swing-by time drew nearer, the predictions were refined and the uncertainties reduced. The later the correction manoeuvre could be delayed, the better the prediction accuracy. Acting against this was the fact that the size of the manoeuvre would increase approximately in inverse proportion to the time between its execution and the time of perigee. Also, in the case of a ground-station contingency whereby the manoeuvre commands could not be sent, provision had to be made for a back-up opportunity using a different station. As a compromise, it was decided to make the critical last manoeuvre two days before closest approach.

There was some leeway in calculating the target point in that the eventual time of encounter with Comet Grigg-Skjellerup did not have to be precisely fixed. This degree of freedom meant that it was possible to perform the correction manoeuvre with a radial thruster alone, even though the direction of the impulse was constrained to lie in the plane normal to the spacecraft spin axis. Consequently, the final selection of the target point, and the time of perigee associated with it, depended upon the latest predictions of the spacecraft's trajectory.

On 28 June, the final target was determined. By 29 June, the Earth's gravity had begun to bend the spacecraft's trajectory and this allowed an accurate estimation of the orbit, which confirmed the results of the previous day. Under the guidance of a tense but confident operations team, the 74 min manoeuvre was executed at 10:00 UTC on 30 June. Soon afterwards, it was established that the change in the Doppler frequency caused by the manoeuvre was very close to the prediction. On 1 July, the manoeuvre parameters could be calibrated. It had underperformed by just 2.6% and the velocity increment (delta-V) direction had been in error by less than 0.5°, which represented excellent performance for a hydrazine system.

The very small size of the final error ellipse reflects the extremely high information content within the tracking data obtained during the swing-by period.

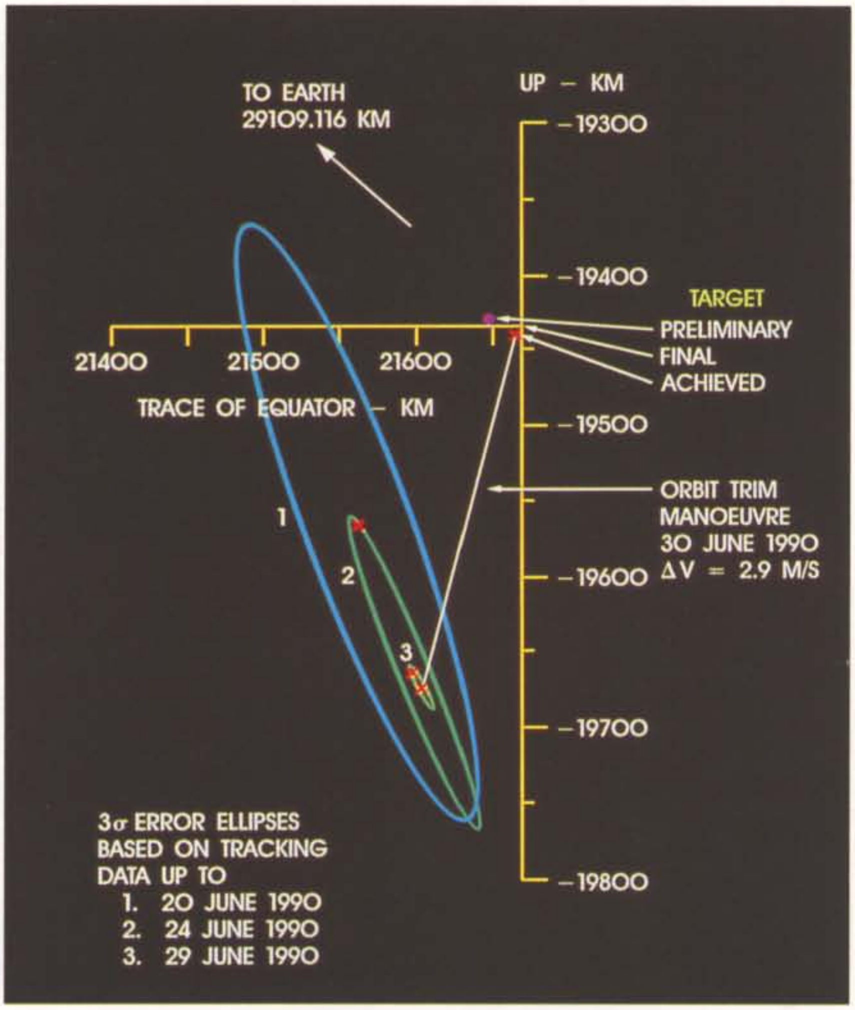


Figure 11. Giotto targetting for Earth swing-by

Earth swing-by

Except near perigee, Giotto's angular velocity around the Earth was lower than the Earth's rotation rate. Therefore, the spacecraft flew in from the east, made one loop over Australia, and receded into deep space flying westwards over south-east Asia (Fig. 12). Perth, acting as the prime ground station, was able to follow the spacecraft up to perigee and beyond, until the shadowing of the LGA became severe and contact was interrupted. This caused no problems since only monitoring of the housekeeping telemetry was being performed.

During the swing-by period, two of Giotto's experiments, the Magnetometer and the Energetic-Particle Analyser, were switched on. The recorded data were stored on board and played back to ground on 5 July. The measurements are still being analysed by the science teams, but preliminary indications are of good-quality data that should supplement our knowledge of the Earth's magnetic- and charged-particle environment.

While Giotto was passing over Australia, night had already fallen on the sub-continent. The spacecraft itself remained continuously sunlit, and so an observer under a clear sky should have been able to follow the pin-point of reflected light as it traversed the heavens. Because of the distance involved, the spacecraft could not have appeared bright and a small telescope, at least, would have been essential. Both professional and amateur astronomers were alerted to the opportunity for sighting Giotto but, at the time of writing, no positive report or, best of all, a photograph has been received.

Second hibernation

As planned, on 7 July, the largest attitude-precession manoeuvre was performed to re-orientate the spacecraft spin-axis through 110° (the orbital effect of this manoeuvre had previously been taken into account in optimising the targetting for the swing-by). By good fortune, it had been possible to choose as the final attitude one that once more allowed communications via the HGA and simultaneously satisfied all the constraints on the attitude during the next hibernation period and the second reactivation, planned for May 1992.

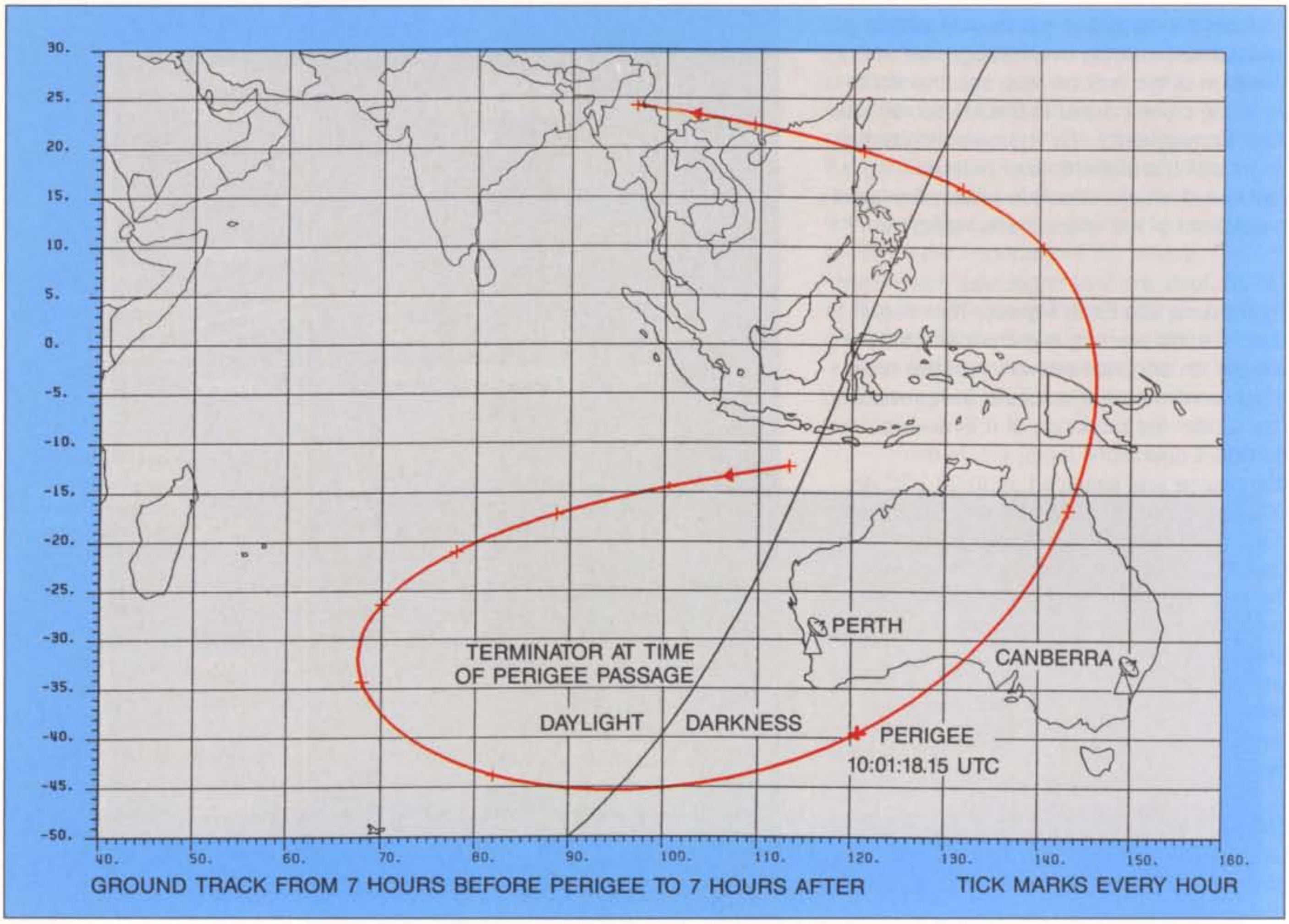


Figure 12. Giotto's ground track during the Earth swing-by

In the foreseen hibernation attitude, it was doubtful whether a star would appear in the star-mapper field of view that was bright enough to be detected. The manoeuvre brought another piece of luck. The attitude achieved was 4° away from that desired – still satisfactory for the hibernation – and with a bright star available for confirming the attitude.

The subsequent determination of the orbit verified the precision of the Earth swing-by trajectory. A radial-pulsed manoeuvre of 0.5 m/s, executed on 16 July, was the final refinement needed to set Giotto on a collision course with Comet Grigg-Skjellerup.

On 23 July, after a further week of tracking, the spacecraft was configured for hibernation. The HGA despin mechanism was turned off and the last telecommand switched off the on-board transmitter.

Outlook

The next stage of the Giotto Extended Mission is a voyage of 1.8 billion km. The orbit can be predicted so well that in May 1992, the spacecraft's position in the sky will be known to an accuracy of two thousandths of a degree and, if no catastrophic failures occur on-board in the meantime, prospects for another successful reactivation are good.

Since the first reactivation, only 7 kg of hydrazine have been consumed, leaving 17 kg in hand, which is more than ample for future orbit and attitude control. Even if contact is never again made with Giotto, it will still fly within 20 000 km of the nucleus of Comet Grigg-Skjellerup, at a relative speed of 14 km/s, with closest approach occurring between 15:20 and 15:25 UTC on 10 July 1992.

The Hipparcos Mission — On the Road to Recovery

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The successful launch of the Hipparcos satellite on 9 August 1989 by Ariane flight V 33 represented the culmination of eight years of development and construction work on a European space mission designed to revolutionise the fundamental astronomical science of measuring the positions of the stars. Never before has there been any attempt to measure stellar positions and motions from space.

Introduction

With the launch of Hipparcos last year, the age of space astrometry was to be ushered in with a global positional-measurement programme of immense proportions – a scientific observing programme of more than 100 000 stars with an expected precision some 100 times better than that routinely achievable from ground-based observatories.

The failure of Hipparcos' apogee boost motor to circularise the elliptical transfer orbit provided by the Ariane launcher, leaving the satellite in a highly anomalous and unplanned configuration, looked likely to bring an untimely end to the years of dedicated effort by the Agency's project team, industry, and the scientific groups that had been involved in this unusual mission.

The objectives of the Hipparcos mission had always been recognised as ambitious and had even been claimed by some to be unattainable. The goals of maintaining the long-term progress that has been established over hundreds of years in measuring star positions, motions and distances (Fig. 1), and of establishing mission objectives that would allow a significant advance in the associated areas of astronomy, meant that Hipparcos had to be capable of measuring the positions of some 100 000 stars to an accuracy of about 2 milliarcsec.

This mammoth task is being addressed by a satellite which, including its payload, is entirely under ESA's responsibility, thereby representing a first for the Agency's Scientific Programme.

Novel features of the satellite's design

The technological requirements imposed upon Hipparcos itself by the novel scientific objectives outlined above were equally demanding, and many aspects of its design, manufacture and operation stretch the imagination. The target angular measurement accuracy of 2 milliarcsec (2/1000 ths of 1 arcsec) is almost too tiny to comprehend; the hair on somebody's head, standing 1 m away from you, grows by this angle in just 1 s! The demands on the satellite subsystems were correspondingly stringent, including the need to control the payload's temperature to better than 0.05 °C.

The optical mirrors for Hipparcos had to be polished to a precision of 1/60 th of a wavelength. Hence, if the size of the mirror were to be scaled up to the size of the Atlantic Ocean, the fluctuations from a smooth surface would nowhere exceed 10 cm in height! The 'beam-combiner' mirror also has the added complexity of being both aspherical and asymmetrical, while the entire set of optical elements has to be held together with alignment tolerances of a few microns.

The attitude control of the satellite is such that the telescope's two fields of view must follow an intricate and predefined scanning law, which involves both scanning and precessional motion. The actual pointing orientation is continuously reconstructed by the onboard computer to an accuracy of about 1 arcsec.

The measurement principle employed by Hipparcos involves measuring the relative separations of stars lying along a strip of sky

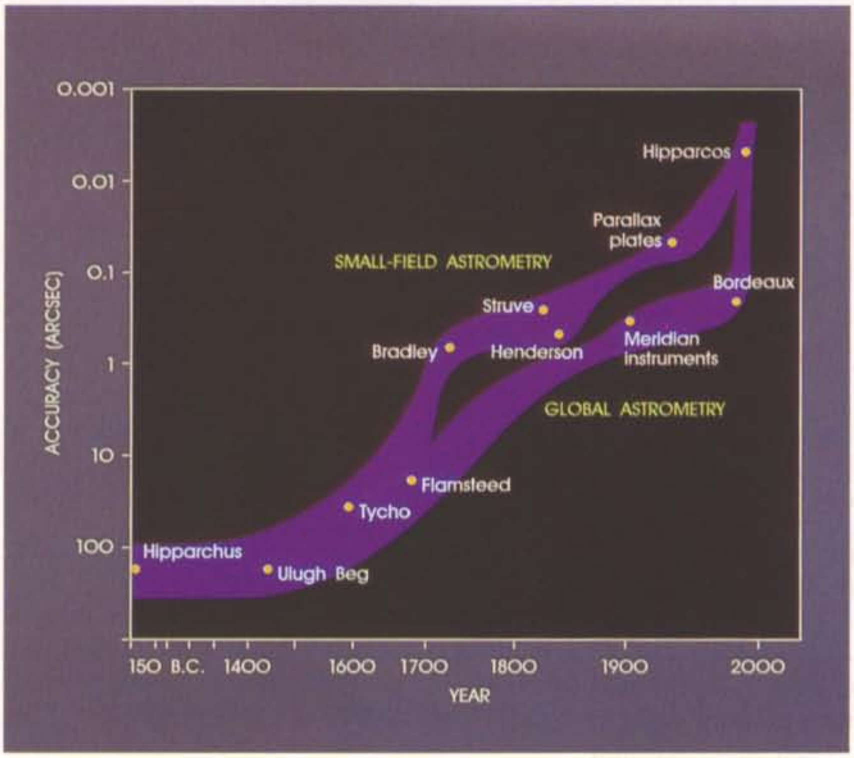

Figure 1. The long-term trend established over hundreds of years in measuring star positions, motions, and distances

about 1° wide. As the satellite rotates about its axis in a period of a little over 2 h, the relative positions of the stars along this great circle are determined. The primary detector, an image dissector tube, located behind the modulating grid, samples the incident starlight 1200 times per second, and switches from star to star 150 times per second. The interpretation of the uplinked programme star file, the observing-sequence generation, the data acquisition, and the onboard attitude control and determination, call for one of the most complex pieces of onboard processing yet achieved on an ESA satellite.

Data are downlinked from the satellite at a rate of 24 kbit/s, pre-processed at ESOC, in Darmstadt (D), and subsequently forwarded on magnetic tape to the scientific institutes carrying out the data reductions. As the measurements accumulate over the mission lifetime, large numbers of such great circles are accumulated at widely separated times and at different angles of intersection. The ultimate stellar reference frame, and the motions and distances of the stars within this frame, are slowly built up by the data-reduction procedure running on the ground.

It is a unique feature of the data reductions that all information acquired during the mission enters the data-reduction process with roughly equal weight. This makes the data-reduction process – the simultaneous determination of many hundreds of thousands of unknowns – undoubtedly the most complex and the largest single data-analysis problem ever addressed in astronomy to date. The size and complexity of the processing task (300 000 lines of software form the core of the FAST Data Reduction Consortium's processing software alone) can be imagined from the quantity of data (some one million million bits of data will be acquired by the satellite over its nominal mission lifetime) and the ultimate precision required.

Scientific participation in the Hipparcos mission

The hardware commitment by ESA and the industrial team (Fig. 2) has been matched by a substantial intellectual, logistical and manpower-intensive commitment from the European scientific community. Through the establishment of four scientific teams, together totalling around 200 scientists from numerous disciplines (astronomers, mathematicians, geodesists, programmers, optical specialists, etc.), interfacing with ESA through the Hipparcos Science Team (Fig. 3), the development of the satellite and payload proceeded in parallel with the preparation of the stellar observing catalogue and the preparations for data reduction. This ensured that the ESA-developed payload would satisfy the most stringent astronomical and data-processing requirements.

The hand-in-hand development of the observing programme, the reduction procedures, and the satellite design led to some remarkable programmatic achievements. Rather than suffering a gradual 'descoping' of the scientific objectives during the development phase, which is not uncommon in space missions as the dual constraints of schedule and cost begin to make themselves felt, the professional management of the project, through the combined efforts of the Agency and its industrial contractors, supported by the scientific consortia, led instead to enhancements in the expected scientific return.

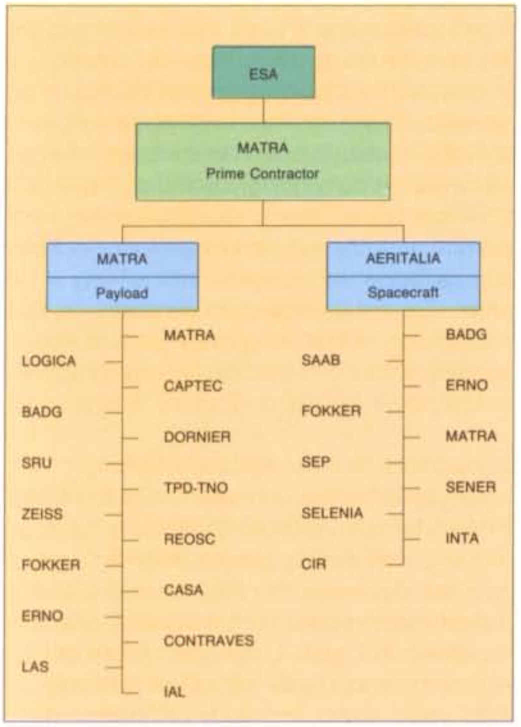

Figure 2. The Hipparcos industrial organisation

The data-reduction teams showed how an enlarged observing programme of 120 000 stars (rather than the 100 000 originally foreseen) could be accommodated at little expense in terms of achievable accuracy. The Tycho experiment (aimed at measuring the positions and undertaking two-colour photometry of an additional 500 000 stars, with a somewhat lower, but nevertheless impressive, accuracy) was moulded from the existing star mappers. Proper control of the error sources, fabrication methods, and operational procedures led to a progressive improvement in the expected astrometric errors as mission development proceeded.

All of this was achieved on schedule (although the launch eventually slipped by a year due to the Ariane launch difficulties in 1988) and at a cost less than 20 % higher than that at which the programme was originally approved by the ESA Science Programme Committee back in 1982. The Prime Contractor, Matra, its co-Prime Contractor, Aeritalia, and their many industrial subcontractors are to be congratulated for their continued cooperation in achieving the best possible scientific mission within the many constraints imposed upon them.

The data-handling and logistical problems associated with the compilation of the Input Catalogue were considerable, and involved the gathering together of the best available ground-based data on each of the 120 000 programme stars, acquired from a large number of sources compiled over many decades, as well as large numbers of new ground-based observations made especially for the Input Catalogue. This Input Catalogue is used for both the observing programme, and for the 'star-pattern recognition' process of the attitude control, and has served its purpose admirably in both respects.

Attitude control

In order to understand the difficulties faced by the revised mission, it is important to have an understanding of the critical link between the stellar measurements, the attitude measurements made onboard the satellite, and the satellite's attitude control.

The Input Catalogue contains the 'approximate' positions of all the stars to be observed by Hipparcos' main detector system. These are uplinked to the satellite in the form of the expected times at which the stars are predicted to cross the 'star-mapper' slit measurement system, based on the nominal attitude of the satellite. The actual star transits across the star-mapper slit system are detected, converted to actual crossing times, and these times then allow the onboard computer to calculate the difference between the nominal and actual satellite attitude.

In between bright-star transits across the star-mapper slit system (every 20 s or so), knowledge of the satellite's attitude is maintained, to about 1 arcsec, by the on-board gyro measurement system (and reconstructed subsequently by on-ground scientific processing to better than 0.1 arcsec). The satellite's real-time attitude, determined by the onboard computer, is then used to 'pilot' the sensitive area of the main detector to track the programme stars as they cross the 0.9° width of the main field of view.

Figure 3. The Hipparcos Science Team

Name	Institute	Main Responsibilities
Prof. P.L. Bernacca	Asiago (I)	Data reductions (FAST)
Dr M. Crézé	Strasbourg (F)	Input Catalogue
Prof. F. Donati	Torino (I)	Data reductions (FAST)
Dr M. Grenon	Genève (CH)	Input Catalogue, photometry
Prof. M. Grewing	Tübingen (D)	Tycho Consortium
Prof. E. Høg	Copenhagen (DK)	Tycho Consortium Leader
Prof. J. Kovalevsky	Grasse (F)	FAST Consortium Leader
Dr F. van Leeuwen	Cambridge (UK)	Data reductions (NDAC)
Dr L. Lindegren	Lund (S)	NDAC Consortium Leader
Dr H. van der Marel	Delft (NL)	Data reductions (FAST)
Mr C.A. Murray	RGO (UK)	Data reductions (NDAC)
Dr M.A.C. Perryman	ESA	Project Scientist
Mr. R.S. Le Poole	Leiden (NL)	Instrument performances
Dr H. Schrijver	Utrecht (NL)	First-look and calibration (FAST)
Dr C. Turon	Meudon (F)	INCA Consortium Leader

The measurement principle also requires that the satellite's scanning motion be as smooth as possible, so that most of the time Hipparcos is drifting freely in space under a subtle balance of perturbing torques. Specially developed low-impulse (20 mN) cold-gas thrusters operating along all three axes are fired to bring the satellite back towards its nominal attitude whenever a deviation of more than 10 arcmin occurs. The attitude-determination, prediction and jet-firing strategy also makes use of an onboard model of the perturbing torques acting on the satellite; for the nominal mission, principally solar radiation pressure.

Launch and the revised mission preparations

The transfer orbit into which the satellite was launched had a period of about 10 h, with Hipparcos reaching an apogee of about 36 000 km, but swinging down to a perigee of just 200 km. This orbit therefore passes through the regions of trapped and highly energetic protons and electrons known as the 'Van Allen belts'. The mission-operations plan called for the firing of the apogee boost motor during the fourth orbit (or as a backup during the sixth orbit), because it was known that the satellite's solar panels would be subjected to more rapid degradation due to these trapped energetic particles than in its planned 24 h geostationary operating orbit.

It soon became apparent that attempts to fire the apogee boost motor were of no avail. Improvised in-orbit diagnostic tests were devised, calling for intensive onboard-software development. These were able to demonstrate convincingly that the firing commands were being received by the satellite and correctly interpreted as electrical signals fed to the apogee motor's firing chain. Thus suspicion soon centred on a malfunction of that firing chain itself, a view subsequently confirmed by the results of the independent Hipparcos Enquiry Board.

In parallel with the continued efforts to understand the failure, members of the ESA Project Team, the ESOC Operations Team, Industry, and the Hipparcos Science Team gathered to assess the situation and identify the problems posed by the elliptical orbit. As shown in Figure 4, the latter were both numerous and initially difficult to quantify. After years of detailed study of operational characteristics in the expected geostationary situation, the problems to be addressed were almost those of an entirely new mission. Moreover, they had to be solved under intense time pressure.

Firstly, the solar arrays were being bombarded and damaged by the protons in the Van Allen belts, and the consensus was that the satellite would run out of power

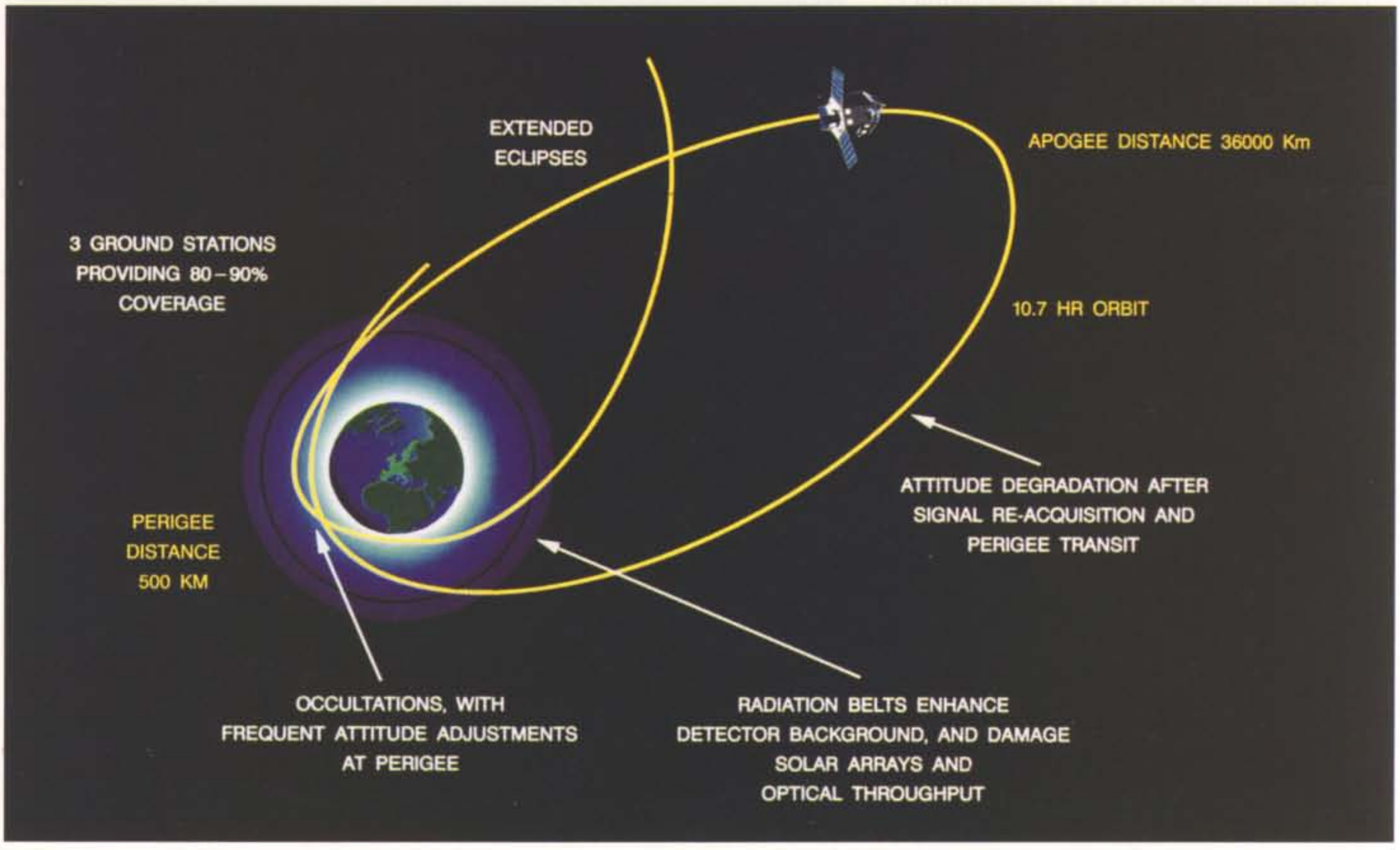

Figure 4. The revised Hipparcos orbit, and the problems associated with it

within a few months. The radiation belts would also contribute to the noise level in the detectors, both degrading the main measurement system and blinding the star-mapper detectors, on which the satellite's attitude control relied. With only one ground station planned to communicate with the satellite (uplinking the observing programme to the satellite and receiving the resulting data) and with no onboard data-storage capabilities, the satellite would be in contact with the ground station for only about 8 h per day.

Not only would this drastically reduce the amount of useful scientific data acquired by the mission but, more critically, the hours during which the satellite was beyond ground-station contact would prevent the onboard attitude-determination process from maintaining the necessary accuracy. Given that these data outages would frequently correspond with perigee passages, the mission prospects looked poor. While in the perigee region, the satellite would be subject to high perturbing torques (the effects of aerodynamic drag and gravity-gradient torques, particularly, greatly exceeding those expected for the nominal mission), and this would further complicate the attitude-determination and control tasks. Long eclipses would be experienced in the elliptical orbit, putting great strains on the power subsystem. It was therefore expected that all, or at least some, of the essential payload functions would have to be switched off during the extended eclipse periods.

Other problems, perhaps not critical to the satellite's survival, but nevertheless severely complicating the mission operations and data acquisition – such as temperature fluctuations of the payload and extended Earth-occultation intervals – cast further doubt on the mission's future. Finally, it was recognised that any onboard anomalies or failures during the long periods out of ground contact could easily have catastrophic consequences, as the satellite was designed on the basis of only short periods without such contact.

It was with these difficulties in mind that a revised mission plan was carefully put into practice. Numerous systems analyses were undertaken, models of the new operating conditions were drawn up, plans for new ground stations to provide better coverage for satellite operation and data acquisition were made, and onboard software changes were made to cope with the new conditions.

After the major recovery mission-design options had been finalised and the necessary decisions made, a series of tense and risky flight-operations activities was embarked upon. The first step was the execution of a newly-designed 'perigee-raising manoeuvre', which was completed one month after the launch. This used the onboard hydrazine fuel system (originally intended for satellite manoeuvres up to the time of station acquisition) to raise the orbital perigee from its launch value of about 200 km to around 500 km (the satellite can now be seen with the naked eye near the equator), and consequently lessened the perturbations acting on the satellite at perigee.

This was followed by the transition from the spin-stabilised phase to the three-axis-controlled phase. This step involved a partial despin, solar-array deployment, hydrazine dumping, complete despin, Sun acquisition, and ultimately routine scanning under gyro control. These critical operations had to be segmented in order to cope with the non-continuous ground-station coverage. The flight operations had to be redesigned to ensure that the satellite was left in a safe configuration before each break in communication.

The execution of these operations represented the two most critical weeks in the recovery of the mission. Despite the added strain caused by the fact that the best station-coverage periods happened to be during the night, everything went flawlessly, and eventually the satellite was confirmed to be in the safe normal mode.

New attitude-control parameters were devised and uplinked, which allowed the satellite's attitude to be maintained reasonably well around perigee. Operational procedures were also developed to determine its attitude after each perigee passage or signal loss, through ground processing of satellite data. The derived satellite attitude parameters were then uplinked to the satellite to set it off again on its stellar measurements.

Payload calibration, originally foreseen to last for 30 days, was then begun and also had to be carried out under difficult conditions. On the one hand there was a sense of urgency to acquire as much scientific information as possible; the minimum everybody wanted was to validate the entire measurement principle and operational concept before the satellite died. On the other hand, all operations were being conducted with short ground-station 'passes', during which the satellite's signal had to be acquired, its attitude determined, a calibration task initiated and completed, and the satellite put into a safe mode once again before the signal was lost. Many passes were too short to be of significant value and some were lost due to high background-radiation levels (due to the high level of solar activity at this time), and so payload commissioning and calibration eventually took about 2 months.

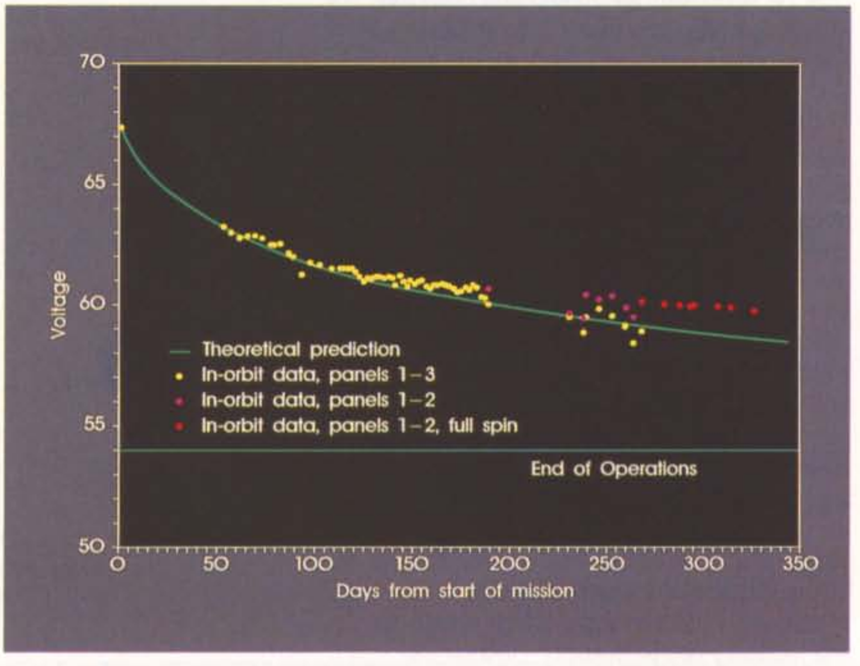

Figure 5. The theoretical (green line) and observed (yellow circles) voltages of the Hipparcos solar arrays since launch. Satellite operations can continue as long as the voltage generated exceeds a minimum of about 54 V. Present indications are that a lifetime of more than three years should be achievable.

The gap in the data between days 190 and 230 corresponds to the long eclipse period, when no in-orbit measurements were made. The subsequent scatter in the data points, due to a malfunctioning temperature sensor, has been corrected by omitting panel 3 from the measurements (red circles), and extending the measurements over a full satellite spin period (orange circles)

Actually, apart from the longer time needed to complete all of the tasks due to the difficult operating conditions, the satellite behaved perfectly, and indeed better than even the most optimistic early expectations.

By the end of November, all commissioning activities had been completed: the main detector had been operated, the data validated, and the mirror focussing (and other payload optimisations) had been completed. The routine data-collection phase began on 26 November 1989. The Perth ground station had been brought into the network by mid-September, and the CNES Kourou station was added in early November, lifting the time during which the satellite could be contacted from the ground from 30 % to about 70 %.

A fourth ground station, the Goldstone 26 m (DSS-16) station in California operated by NASA, was brought into the network in early May 1990, and resulted in full telecommand and telemetry contact with the satellite for about 90 % of the time. The Kourou station, whose coverage was largely superseded by the Goldstone station, was taken out of the network in mid-July 1990. Gaps when the satellite is not visible from any of the ground stations now rarely exceed 1 h, and this means that as each ground station hands over to the next, like some grand space relay race, the satellite-attitude knowledge can be largely preserved, and the scientific observations can continue.

Even with the nominal operating configuration, the Hipparcos mission would have been one of the most operationally complex missions ever undertaken by the Agency, requiring continuous interaction between ground and satellite. The apogee-boost-motor failure vastly increased the operational complexity still further, and the additional ground stations in particular have led to an associated increase in the cost of the misson operations.

Routine operations

By the end of 1989 the satellite was providing vast quantities of scientific data – enough to fill ten high-density magnetic tapes per week – and the data analysis and interpretation was well underway. The long-term mission prospects were still unclear, however, due to two main problems: the degradation of the solar arrays, and the impending long-eclipse phase of mid-March 1990.

It was not until the end of 1989 that a good picture of the expected lifetime of the satellite began to emerge. Special operational procedures were necessary to allow in-flight measurements of the current and voltage characteristics of the solar arrays to be made, procedures were designed to normalise the resulting measurements to standard values, and the solar-array experts at ESTEC had to develop models of the solar-array degradation based on both the known characteristics of the materials and the known particle-radiation environment in the geostationary transfer orbit.

Solar flares, and the orbital evolution, complicated the interpretation, and the initial dramatic decrease observed in the voltages gave considerable cause for concern. It soon became evident, however, that this drop was the initial signature of an exponential decay. The predictions were soon shown to be in good agreement with the observations, and this understanding led to an expected lifetime of more than three years for the mission, from the solar-array-degradation viewpoint (Fig. 5).

The major remaining concern was the long eclipse season occurring in March 1990. The satellite's batteries had been designed for geostationary-orbit operation, where the longest eclipse (during which the satellite must rely on its batteries for power) would last for only about 5 % of the orbital period. In the revised mission, the orbital period was less than half, and the maximum eclipse duration was about 50% longer than, that in the geostationary orbit, so that more than 15% of the orbit had to be battery-powered.

Careful power monitoring and contingency procedures were developed that would allow certain sections of the payload to be shut down if battery recharging was not completed before the start of the next eclipse. Eventually, the maximum eclipse duration (which should not be experienced again during the next three years) was passed with a margin of just 5 min between the end of charge and the start of the next eclipse. Scientific observations proceeded without interruption, and the mission continued with yet greater optimism than had been previously possible.

The scientific programme

Although the mission had not been planned for anything other than geostationary-orbit operation, there is no physical reason why the stellar positional measurements could not be conducted from the hostile orbit in which the satellite found itself (background noise and perturbing torques permitting), since the measurements are generated by the attitude scanning motion. In terms of orbit characteristics, it is only necessary that the satellite position be known within about 1 km at any instant, and its velocity within about 20 cm/s.

Fortunately, therefore, it was not necessary to modify the astronomical observing programme – the payload functioned within specification, and the 120 000 programme stars were retained and observations of them proceeded nominally, with the exception of the loss of some observing time, as noted above. Actually, not only was it unnecessary to modify the observing programme, but it would have been extremely difficult to do so – the measurements and the corresponding data reductions are 'global' in nature, each star observation tying up with every other, every scientific target star also being an element of the basic reference frame that Hipparcos should be establishing.

As of November 1990, one year of Hipparcos data has been acquired and is in the course of being processed. More than 100 000 000 000 bits of data have been acquired, covering all of the programme stars (on average 10–20 times each), and the 50 minor planet and other Solar System bodies (Titan, Europa, Uranus, Neptune, etc.) contained in the observing programme (Fig. 6).

The data quality is such that the brightest quasar, 3C 273, previously considered too faint to be observable by the satellite, was added to the observing programme in July

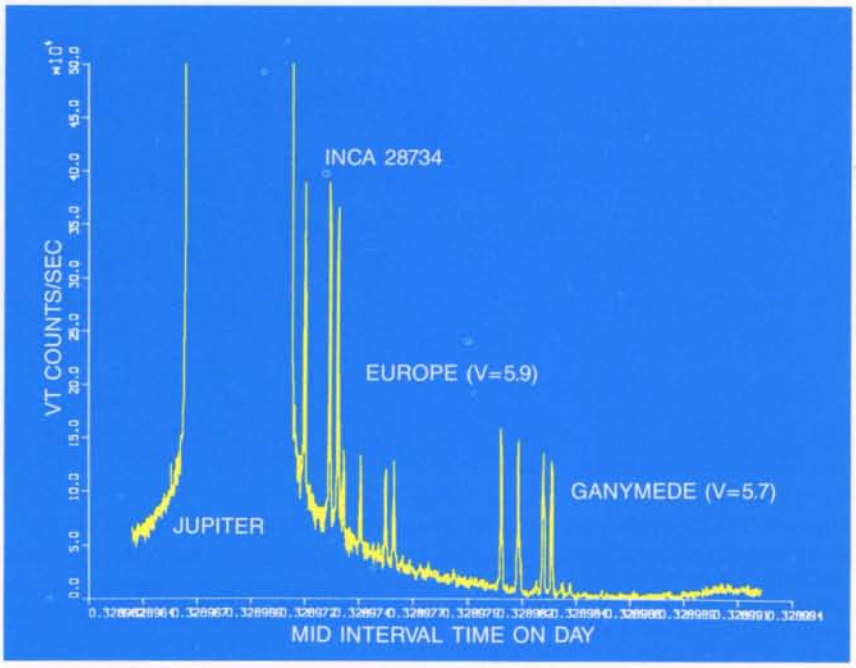

Figure 6. The passage of Jupiter and its moons across the star-mapper's slit system

1990. At 13 mag, the object is very faint, but will allow a direct tie in of the Hipparcos reference frame to an extragalactic reference frame.

Many difficulties in the data interfaces between ESOC and the data-reduction teams had to be overcome because of the anomalous operational conditions, but the data analysis is now proceeding in a more-or-less routine manner. The data are of spectacular quality: high-quality star positions, photometric measurements, and double-star discoveries are being made (Fig. 7).

Mission prospects

The satellite lifetime, from the point of view of the solar arrays, should now exceed three years from the start of the routine data-acquisition phase. There is enough nitrogen gas onboard to allow the attitude-control system to function for about four years,

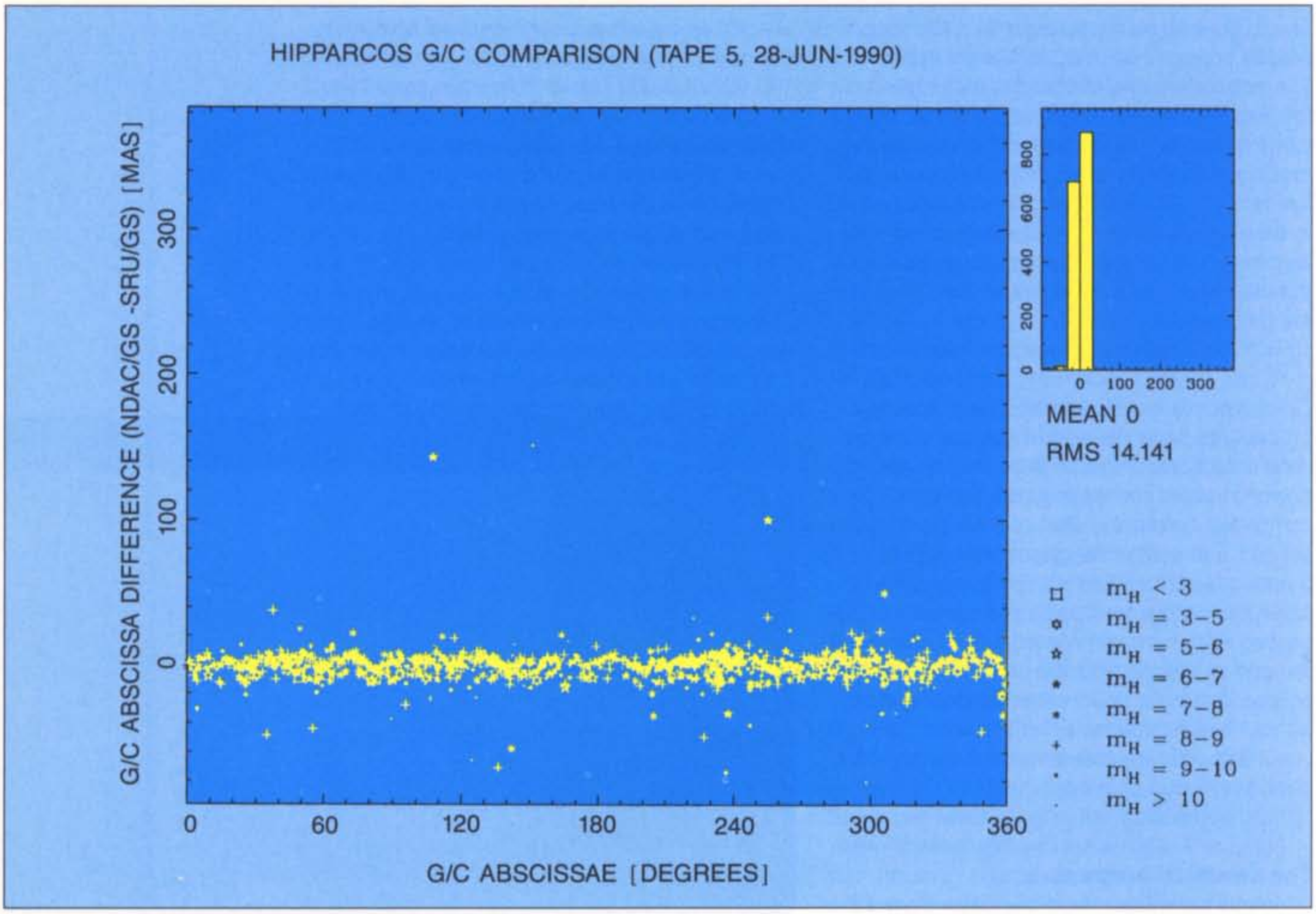

Figure 7. This figure illustrates the status of the comparisons between the great-circle results from the Hipparcos NDAC and FAST data-reduction teams. The abscissa is the great-circle coordinate in degrees, and the ordinate gives the difference between the two reductions in milliarcsec.

Some known effects have not yet been taken into account in these results, but they show that differences between the two reductions currently amount to less than about 10 milliarcsec.

The great-circle comparison results were derived by Dr H. van der Marel (Delft) on the basis of data supplied by the FAST and NDAC Consortia (led by Prof. J. Kovalevsky, Grasse, and Dr L. Lindegren, Lund, respectively).

even though much more fuel is used up in maintaining the attitude-control system throughout the high perturbing torques of the perigee region.

There are many challenges still to be overcome, especially in the area of the data processing, but the expectation is now that the original target scientific goals of 2 milliarcsec accuracy in the positions, proper motions and parallaxes (for a star of 9 mag) can still be achieved. The present predictions even suggest that these target accuracies can be somewhat bettered. Thus, even with the present orbital difficulties, a lifetime of three years will yield all of the science, and more, that the mission had been designed to fulfil. The satellite performances are so good that, had Hipparcos been in its intended orbit, the results would have been substantially better than specified – a great tribute to the satellite designers and constructors, and to all those involved in the mission preparations.

Conclusions

The Hipparcos Programme suffered one very major setback which looked likely to threaten the successful outcome of the entire mission. Its fate hung in the balance until early 1990, when many aspects of the revised mission became much clearer, and realistic long-term accuracy predictions could again be considered. As the days and weeks now pass with more and more data being successfully acquired, the outlook looks promising.

The satellite is performing in an outstanding manner, and the entire mission concept has been fully validated. This is a great testimony to the years of feasibility studies made by the scientific community before the mission was accepted by ESA, and to the work of all parties (ESA, industry and the scientific teams) involved in the detailed design, manufacture, testing and operation of this unique astronomical mission.

Olympus Manoeuvres in Transfer Orbit — An ESA First

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The Olympus spacecraft was launched on 12 July 1989 by the last of the Ariane-3 vehicles. During the geostationary-transfer-orbit phase, a novel series of fifteen attitude manoeuvres were performed with the spacecraft before its apogee engine was fired during the fourth transfer orbit. The purpose of these manoeuvres was to calibrate the spacecraft's gyroscopes in order to achieve an accurate attitude throughout the apogee-engine firing.

Introduction

Since 1968, ESA has successfully supported the launch of twenty-six spacecraft designed for a variety of scientific and applications missions, fourteen of which were injected into a geostationary transfer orbit (GTO). During the geostationary transfer orbit phase, these fourteen spacecraft shared a common characteristic: all were spin-stabilised, and only the orientation of their spin axis was controlled.

Olympus was the first ESA spacecraft to be three-axis-stabilised in geostationary transfer orbit (i.e. orientation of three mutually perpendicular axes controlled). For Olympus, this three-axis attitude control was achieved using a set of four gyroscopes. The three primary units are aligned with the spacecraft's roll, pitch and yaw axes (Fig. 1); the fourth, equally inclined to these three spacecraft axes, is carried for redundancy purposes and is called the 'skew gyroscope'. The latter can substitute for any one of the three primary gyroscopes should a failure occur.

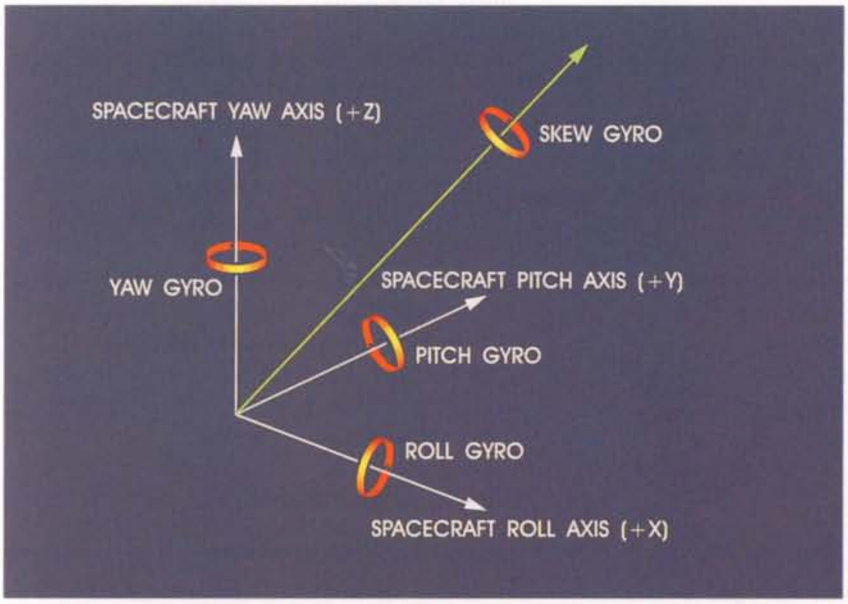

Figure 1. Gyroscope alignment

The function of the gyroscope pack is to measure the spacecraft's rotational rates about its roll, pitch and yaw axes. These measured rates are then integrated by onboard software to determine the spacecraft's roll, pitch and yaw angular displacements from an initial attitude. The angular displacement errors are monitored onboard, and when they reach a pre-defined limit the appropriate reaction-control thrusters are fired to reduce them. In this way, the spacecraft can maintain any desired attitude.

The fifteen Olympus spacecraft attitude manoeuvres (Table 1) were also controlled using the gyroscope pack. A manoeuvre is defined by calculating the required angular accelerations about the spacecraft axes and the manoeuvre duration. This information is uplinked to the spacecraft. The onboard software controls the firing of the reaction-control thrusters whilst monitoring the gyroscope measurements to ensure that the necessary acceleration profile is followed. This method avoids any manoeuvre errors due to thruster over/under-performance. Between gyroscope calibration manoeuvres, the spacecraft was kept in a cruising attitude (−Z-axis Sun-pointing, and +Y-axis normal to the orbit plane and pointing south), which provided optimum ground-station coverage and solar-array power.

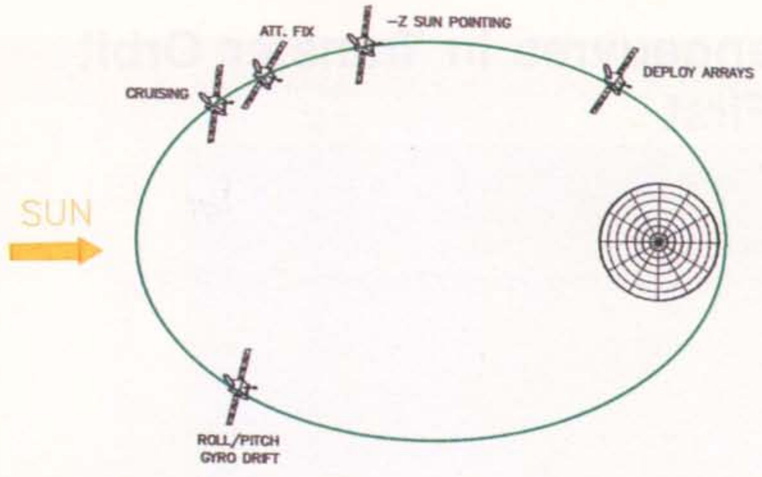

Figure 2a. First transfer orbit

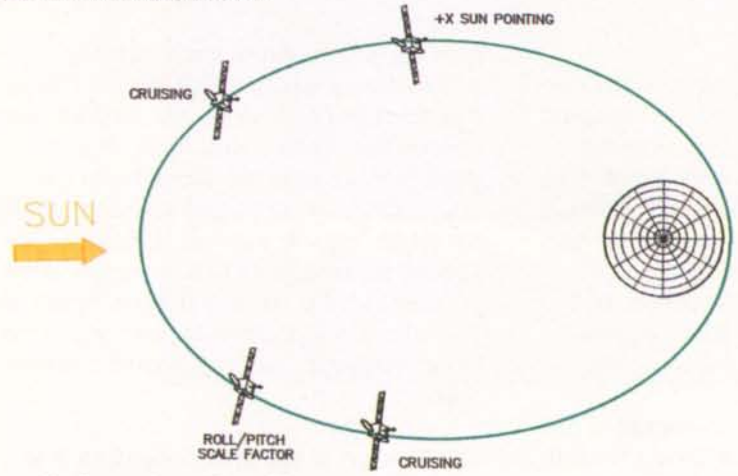

Figure 2b. Second transfer orbit

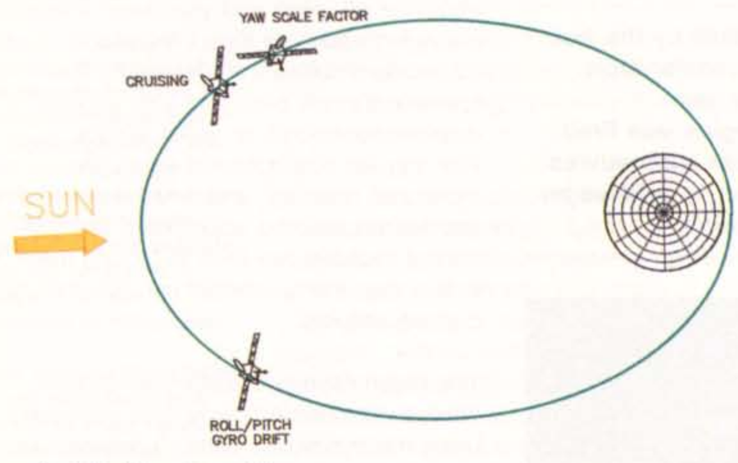

Figure 2c. Third transfer orbit

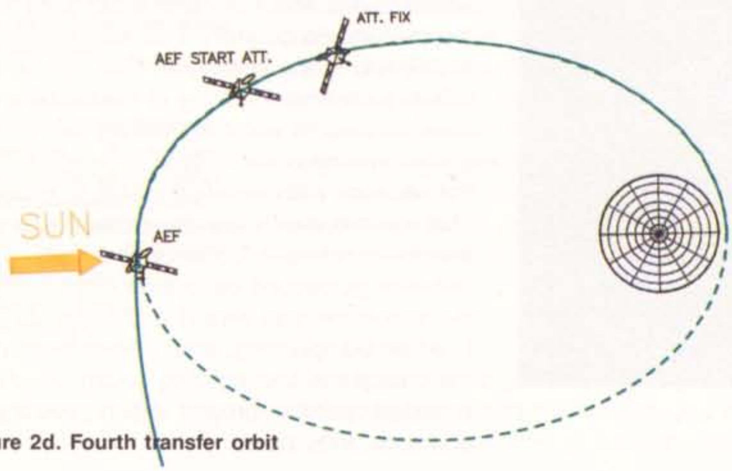

Figure 2d. Fourth transfer orbit

The Ground Control Centre at ESOC monitored the manoeuvres by means of telemetry data from the spacecraft's gyroscopes and optical sensors. Olympus carries three digital Sun sensors and two infrared Earth sensors, providing data from which the Sun and Earth directions as seen from the spacecraft can be calculated.

After completing the fifteen attitude manoeuvres, Olympus was injected into a near-synchronous orbit by firing its apogee engine for approximately 100 min, whilst performing a very slow pitch slew manoeuvre to increase the efficiency of the firing.

This apogee-engine firing lasted a lot longer than that for a conventional solid-fuel apogee boost motor because Olympus uses a bi-propellant fuel system, which employs monomethyl hydrazine as the fuel and nitrogen tetroxide as the oxidiser. The fuel and oxidiser are stored separately in two spherical tanks which feed both the reaction-control thrusters and the apogee engine. This system has the advantage that propellant not used in the apogee-engine firing is available for use by the reaction-control thrusters during the spacecraft's geosynchronous-orbit operations. Moreover, if the apogee engine had failed, Olympus would still have been able to reach geosynchronous orbit by using its reaction-control thrusters.

Geostationary-transfer-orbit sequence

The attitude manoeuvre operations performed during Olympus' four transfer orbits are illustrated in Figure 2.

Initial attitude determination

After separation from the Ariane-3 launch vehicle, the spacecraft onboard control loops automatically damped out the initial rotational rates and manoeuvred the spacecraft to a −Z-axis Sun-pointing attitude. The solar arrays were then deployed to provide power for the onboard subsystems. At this stage there was no knowledge of the orientation of the spacecraft's X- and Y-axes, and Olympus' overall attitude was therefore unknown. The spacecraft was commanded to perform two slew manoeuvres to enable its infrared earth sensor to find the Earth whilst keeping the Sun in the digital sun sensor's field of view.

Figure 3 shows the geometry after the spacecraft's separation from the launch vehicle. Using the predicted spacecraft orbit based on the expected performance of the Ariane-3, the angle (η) between spacecraft and Earth and spacecraft and Sun can be determined. The spacecraft was commanded to perform a rotation of magnitude $(180° - \eta)$ about its Y-axis. As the spacecraft was originally −Z Sun-pointing, this manoeuvre caused its +Z-axis to lie on a cone whose arc intersects the centre of the Earth. The second manoeuvre was defined so that the +Z-axis swept out this cone. With the infrared earth sensor mounted on the +Z-face of the spacecraft, this coning manoeuvre eventually brought the Earth into its field of view. The full three-axis attitude was calculated once Earth and Sun vector data were simultaneously available, taking into account the gyroscope offset angles.

Gyroscope calibration

After the spacecraft's attitude had been established, a series of manoeuvres were carried out to calibrate the gyroscopes, to allow a high spacecraft-attitude accuracy to be maintained throughout the apogee-engine firing and during manoeuvres. This calibration involved estimating the gyroscope drift rates and scale factors.

Gyroscope drift-rate calibration

The gyroscope drift rates affect the accuracy of the gyroscope measurements over long periods and are normally modelled as so-called 'constant-rate biases', i.e. the error in the gyroscope measurements increases linearly with time.

Once Olympus' attitude had been calculated during the first orbit, the spacecraft was manoeuvred into its cruising attitude, defined as the −Z-axis Sun-pointing and +Y-axis normal to the orbit plane pointing south. In this configuration, both the X- and Y-axes were perpendicular to the Sun direction, so that the roll and pitch gyroscope drift rates could be calibrated simultaneously. This configuration was maintained for about 50 min, whilst onboard software compared the angular estimates derived from the gyroscope measurements with those from the digital-sun-sensor measurements.

The difference between the results at the start and end of the calibration, divided by the time interval, gave the apparent gyroscope drift rate as seen by the spacecraft. Ground software used to process the data also corrected for the apparent motion of the Sun during the calibration period, to give the true gyroscope drift rate.

A similar process was also performed for the yaw gyroscope on the ascent to apogee 2 after the spacecraft had been manoeuvred from its cruising attitude to a +X Sun-pointing attitude, such that the Z-axis was perpendicular to the Sun's direction. The spacecraft was manoeuvred back to the cruising attitude after the drift rates for all three primary gyroscopes had been calibrated.

On the descent from apogee 3, the drift rates for both the roll and pitch gyroscopes were recalibrated. This was done because these gyroscopes were used during apogee-engine firing to control the thrust vector, and any resultant drift rates would have a significant effect on the performance of the firing.

Gyroscope scale-factor calibration

The gyroscope scale factors affect the accuracy of the measurements during a manoeuvre and are normally modelled as a constant factor. The manoeuvre error is therefore directly proportional to the slew angle demanded.

The Olympus gyroscope scale factors were determined by first manoeuvring the spacecraft to an initial attitude such that the gyroscope axis of interest was perpendicular to the Sun vector. This initial attitude was

Table 1. The fifteen apogee manoeuvres performed with Olympus in geostationary transfer orbit

Manoeuvre no.	Event	Location
1	Pitch slew for Earth aquisition	Before apogee 1
2	Coning slew for Earth acquisition	
3	Slew to cruising attitude	
4	Slew to +X axis Sun-pointing	After perigee 1
5	Slew to cruising attitude	Before apogee 2
6	Pitch-gyro scale-factor calibration slew	After apogee 2
7	Slew to start of roll-gyro scale-factor calibration	
8	Roll-gyro scale-factor calibration slew	
9	Slew to cruising attitude	Before perigee 2
10	Slew to start of yaw-gyro scale-factor calibration	After perigee 2
11	Yaw-gyro scale-factor calibration slew	
12	Slew to cruising attitude	Before apogee 3
13	Slew to Earth-pointing	After perigee 3
14	Slew to apogee-engine-firing start attitude	
15	Slew during apogee-engine firing	

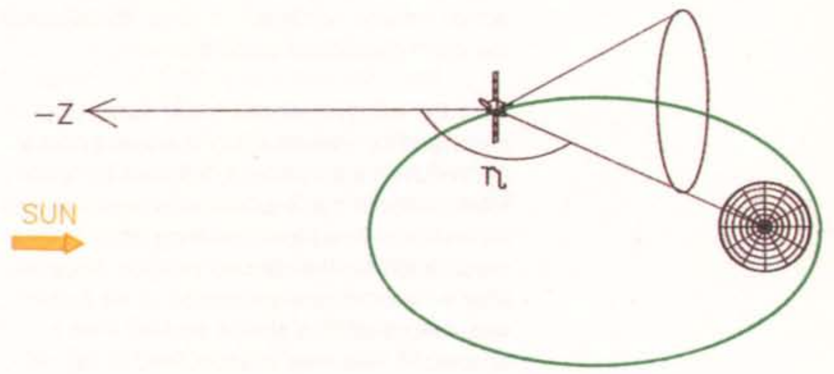

Figure 3. Earth acquisition in transfer orbit

selected so that a subsequent calibration manoeuvre, which was a pure rotation about the gyroscope axis, would not cause the Sun to leave the digital sun sensor's field of view.

The scale factor is defined as the ratio of the actual rotation achieved, divided by the rotation demanded. For increased accuracy, the calibration manoeuvre length should be as large as possible. For Olympus, a 50° rotation was selected for the scale-factor calibration manoeuvres to provide a safety margin relative to the 64° field of view of the digital sun sensor.

After apogee 2, with the spacecraft in cruising attitude, the pitch-gyroscope scale factor could be calibrated by simply performing a 50° rotation about the Y-axis. Ground software then processed the digital-sun-sensor measurements to determine the actual rotation achieved, in order to calculate the pitch-gyroscope scale factor.

Next the roll gyroscope's scale factor was calibrated by manoeuvring the spacecraft to the required start attitude, followed by a 50° rotation about the X-axis. The spacecraft was then manoeuvred to its cruising attitude in preparation for the second perigee pass, after which the yaw-gyroscope scale factor was calibrated in a similar manner. The spacecraft was then manoeuvred to its cruising attitude once again before apogee 3.

Apogee-engine firing

After the third perigee, the full three-axis spacecraft attitude was recalculated by manoeuvring Olympus into an Earth-pointing attitude. This was done to eliminate errors accumulated since the first attitude determination. The spacecraft was then manoeuvred to the apogee-engine-firing start attitude, as determined by the associated optimisation software. It was estimated from the sensor measurements that the attitude achieved at the end of this manoeuvre was within about 0.1° of the desired attitude.

One minute before firing the engine, the spacecraft was commanded to rotate at a constant rate about its pitch axis, which had the effect of altering the thrust vector during the burn to increase the efficiency. The firing itself, which was optimised to minimise the fuel required to reach the target on-station position, lasted 103 min 24 s, with a pitch slew rate of 10.93 deg/h. The manoeuvre was completed 1 min after the firing ended.

Software support

A completely new flight-dynamics software system was developed by ESOC's Orbit Attitude Division to support the geostationary-transfer-orbit operations described (Fig. 4). It has three subsystems, for 'manoeuvre support', 'attitude determination' and 'gyroscope calibration', and its main tasks are as follows:

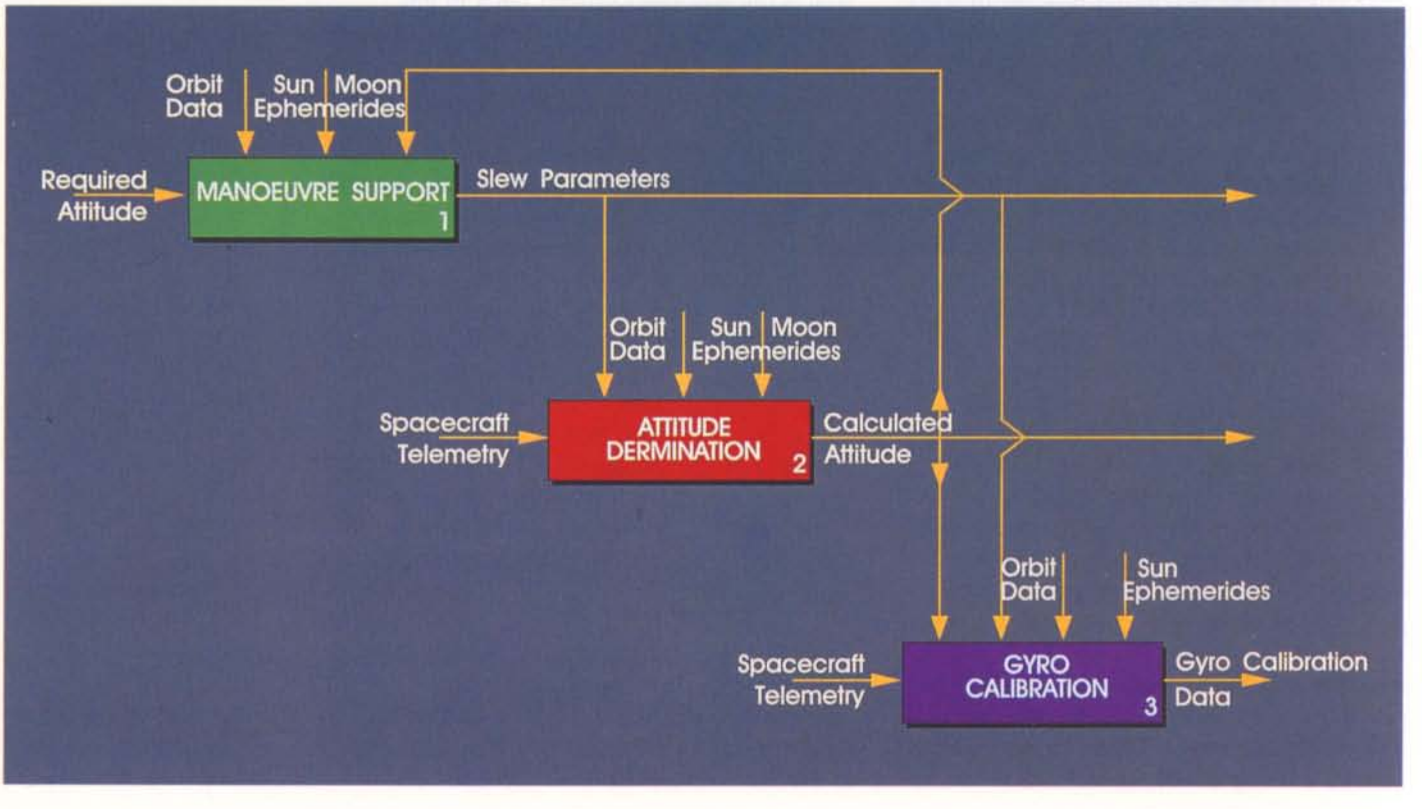

Figure 4. Software subsystem overview

- *Slew-manoeuvre calculation:* Various types of slew manoeuvre (either to a prescribed final attitude, or relative to the current attitude) were performed during the geostationary transfer orbit, based on a menu of choices presented to the operator (Fig. 5). The software also produced the slew commands for subsequent uplinking to the spacecraft.

- *Earth-acquisition support:* The software provided tabular data for the spacecraft altitude, co-linearity angle (angle between spacecraft and Sun, and spacecraft and Earth vectors) and the required slew data for operator-defined times. Checks for possible Moon blinding of the infrared earth sensor were also made.

- *Attitude determination:* This software determined the initial attitude after Earth acquisition and provided continuous attitude estimates throughout the geostationary transfer orbit. The attitude could only be updated using Sun vector information until a second Earth acquisition was performed during the fourth orbit.

- *Attitude prediction:* Provided an estimate of the attitude for any future time using planned manoeuvre data. The attitude during a manoeuvre was also predicted, together with sensor outputs.

- *Slew-manoeuvre monitoring:* During the manoeuvres, software was used to compare predicted and measured sensor outputs to ensure correct functioning of the slew. Predicted and measured attitudes were displayed together with the initial and target attitudes of the manoeuvre.

- *Gyroscope drift-rate calibration:* The gyroscope drift rates were calculated interactively during the 50 min periods when the onboard drift-rate algorithm was running. Corrections for the apparent motion of the Sun were made, and statistical techniques were used to remove noise from the data.

- *Gyroscope scale-factor calibration:* This software compared the measured slew path length as determined from the digital-sun-sensor data with the demanded slew, to calculate the onboard scale-factor error.

- *Event prediction:* This software calculates significant events such as: station coverage, antenna coverage, Moon blinding of the infrared earth sensor, and digital-sun-sensor coverage criteria. It was used as a mission-planning tool.

Slew Selection Menu

SELECT SLEW OPTION 1 – 9

1 AEF ATTITUDE
2 SET – Z AXIS SUN POINTING WITH Y AXIS NORMAL TO ECLIPTIC
3 SET + Z AXIS EARTH POINTING WITH Y AXIS NORMAL TO SUN LINE
4 SET + Z AXIS EARTH POINTING WITH Y AXIS NORMAL TO ORBIT
5 TARGET ATTITUDE (POINTING FRAME)
6 TARGET ATTITUDE (INERTIAL FRAME)
7 ROTATION AXIS/ANGLE
8 ROTATION AXIS/ROTATION RATE
9 TARGET DSS OUTPUT

Figure 5. Slew selection menu

Conclusion

The Olympus Attitude and Orbit Control Subsystem (AOCS) functioned very well throughout all of the above manoeuvres, providing stable attitude control in the geostationary transfer orbit and throughout the apogee-engine firing. The complex series of slew manoeuvres were all performed as predicted, which enabled the spacecraft's gyroscopes to be precisely calibrated. This in turn meant that an accurate attitude was indeed achieved for Olympus prior to the apogee-engine firing.

The new flight-dynamics software, which performed flawlessly in supporting the complex activities during the geostationary transfer orbit, is currently being adapted to support the Italsat spacecraft due to be launched in January 1991.

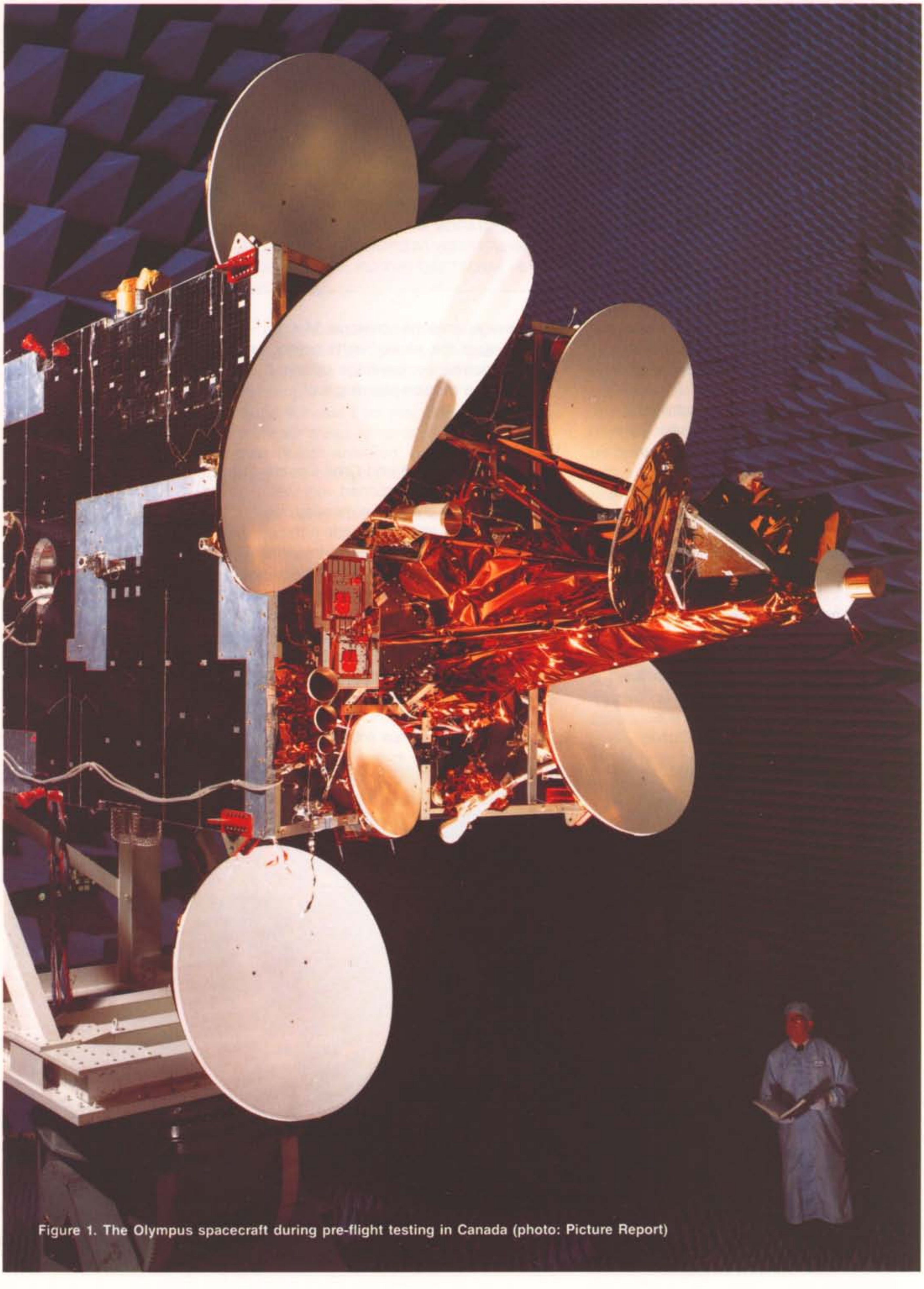

Figure 1. The Olympus spacecraft during pre-flight testing in Canada (photo: Picture Report)

The Olympus Utilisation Programme

C.D. Hughes
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The Olympus-1 satellite, launched in 1989, has provided capacity for communications and broadcasting in three important frequency bands together with beacon signals for propagation experiments. A Utilisation Programme has been established to organise and promote the use of the satellite. This article describes the first year of the Utilisation Programme and its future development.

The Programme includes broadcasting activities in the development of new public services and a wide range of telecommunications activities in the Specialised Services and 30/20 GHz frequency bands. A number of special demonstrations have also been conducted, several of which have made use of two or more of the Olympus payloads simultaneously.

Introduction

On 12 July 1989, the Olympus-1 technology satellite (Fig. 1) was launched from French Guiana by an Ariane-3 launcher and successfully put into geostationary orbit.

This event had been eagerly awaited both by the European Space Agency, who commissioned the spacecraft, and by the Consortium of European and Canadian companies led by British Aerospace who built it. The development and testing of this, the largest civil communications satellite ever launched, had taken longer than anyone expected; but, for the ESA engineers who carried out the satellite's in-orbit testing, there was good news in store.

The complex and versatile spacecraft operated very well indeed. In fact, the platform and payloads outperformed specifications by a considerable margin in nearly all areas. Receive sensitivity, radiated power and satellite-platform stability, in particular, were even better than specified. Despite one or two early failures – the loss of one back-up broadcast high-power tube and the loss of a back-up propagation beacon travelling wave tube amplifier – all the services provided by Olympus remained intact.

It was therefore possible to envisage a wide-ranging utilisation programme which would provide communications and broadcasting facilities to many organisations, enabling them to develop new services with satellite capacity which is in principle free-of-charge.

The Olympus platform was designed to carry a very large commercial payload. However, since Olympus-1 was intended as a demonstration mission to prove a new generation of technology, it contains a mixture of possible payload elements for future programmes. There are four quite distinct payloads, each with its own set of antennas, namely:
- the Broadcast Payload
- the Specialised-Services Payload
- the 30/20 GHz Payload
- the Propagation Payload.

Facilities provided by Olympus-1

The Broadcast Payload

Olympus provides two high-power Direct-to-home Broadcast Service (DBS) channels to Europe. One is presently directed towards central Europe, the other towards Italy. Both are steerable and can be moved to other positions by telecommand. The present pointing of the beams, which is a compromise between the various interests of the users and the regulatory authorities, is shown in Figure 2.

The power available in each channel is quite high (64 dBW peak EIRP) which means that very small ground antennas, of about 30 cm diameter, can be used in the middle part of the coverage, that is, in the whole of central Europe. At the edge of the extended region shown in Figure 2, the antenna diameter required is approximately 1.2 m.

The Specialised-Services Payload

The Specialised-Services Payload (Fig. 3) has four channels, each of which has a nominal bandwidth of 18 MHz. Two of the channels can be switched to a bandwidth of

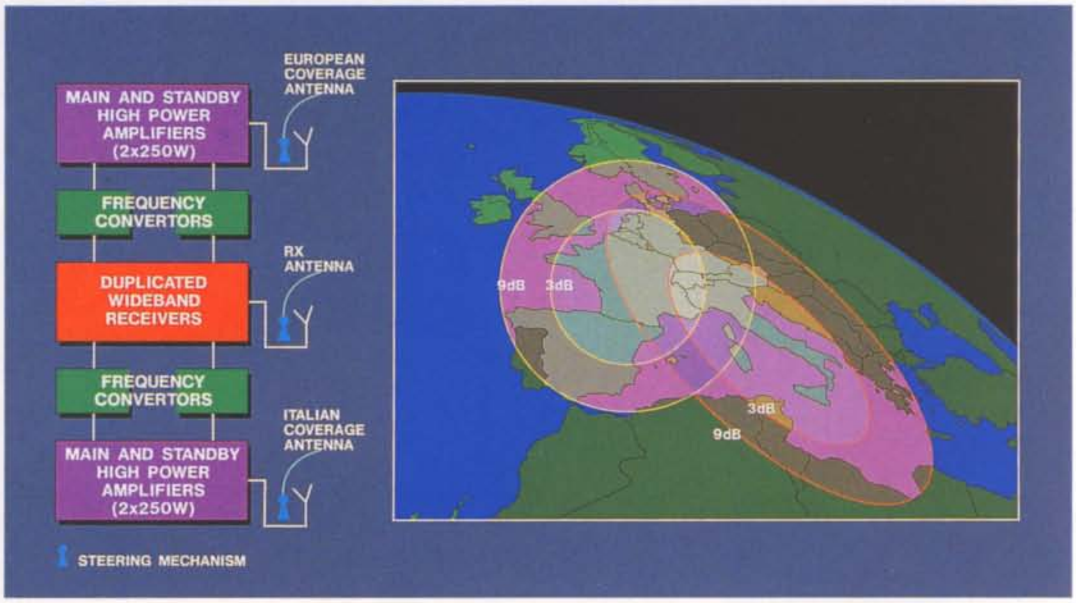

Figure 2. Coverage and simplified schematic of the Direct-Broadcast Payload

36 MHz when necessary. There are five separate uplink beams to the repeater system and five downlink beams. These use a common feed cluster and a steerable reflector. The receive and transmit sections of the four repeater chains are separated by a 4×4 switch matrix, which can be operated either in a static or dynamic mode. The dynamic mode enables experiments with Satellite-Switched Time-Division Multiple Access (SS-TDMA) to be undertaken.

Two possible frequency bands are employed in the uplink, 13.0–13.25 GHz and 14–14.3 GHz. The downlink frequency bands are in the range 12.5–12.75 GHz. The peak Effective Isotropic Radiated Power (EIRP) of each of the beams is 52 dBW.

The 30/20 GHz Payload

This payload (Fig. 4) provides two 40 MHz bandwidth channels with an up-path in the 30 GHz region and downpath at approximately 20 GHz. There is also an alternative wide-band capability (bandwidth 700 MHz) which has been included for certain specialised experiments. There are two spot beams, each with a beamwidth to the 3 dB contour of one degree. Both beams can be steered independently over a very wide coverage range by means of mechanical steering mechanisms.

There are three output travelling-wave-tube amplifiers, each having an output power of 30 Watts, arranged in a redundant configuration. The EIRP at beam centre is approximately 56 dBW which permits the use of small-diameter earth stations for most applications.

The Propagation Payload

This payload provides three beacon signals at frequencies of approximately 12 GHz (B0),

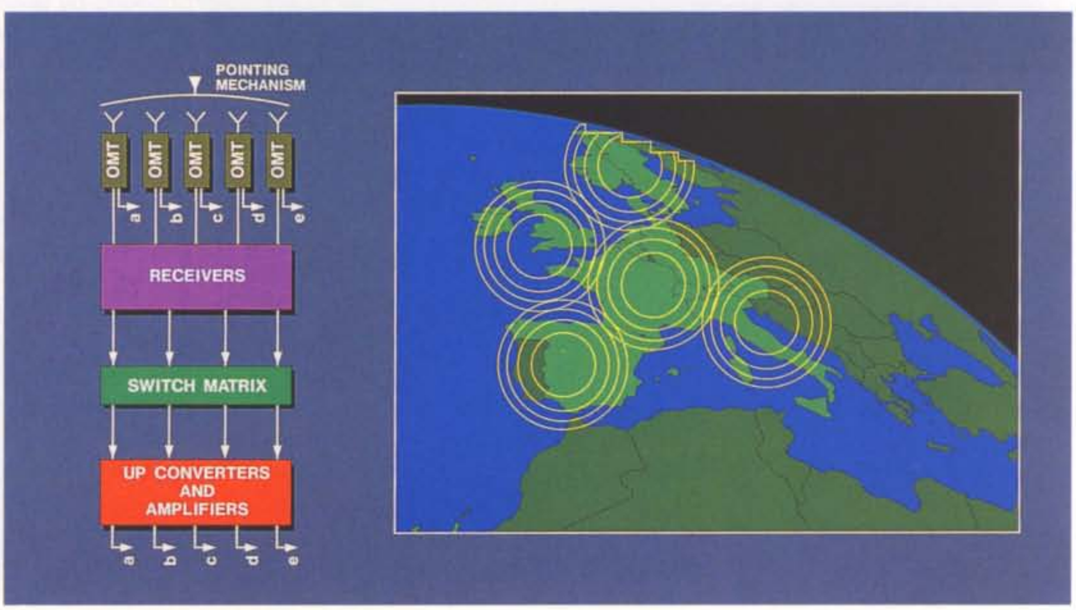

Figure 3. Coverage and simplified schematic of the Specialised-Services Payload

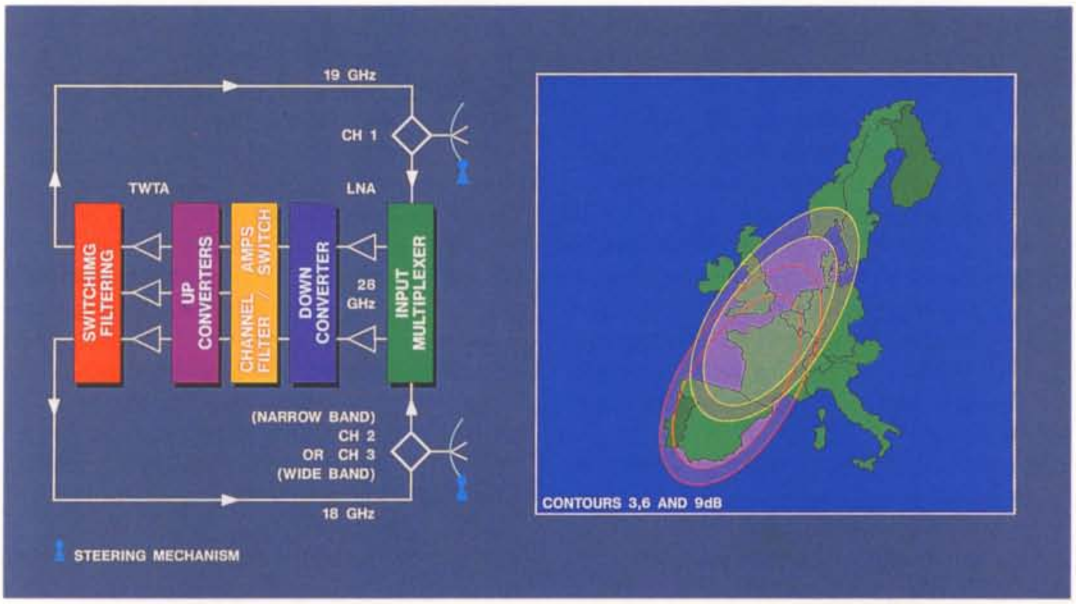

Figure 4. Coverage and simplified schematic of the 30/20 GHz Payload

20 GHz (B1) and 30 GHz (B2). The beacons are all linearly polarised and accurately aligned with each other in polarisation. The B1 (20 GHz) beacon can be switched by telecommand between two orthogonal polarisations or made to switch automatically between polarisations at a rate of approximately 1 kHz. This feature enables accurate measurements to be made of differential polarisation with suitable receiving equipment. The B0 beacon has a global coverage with a minimum EIRP within a coverage of 10 dBW. The B1 and B2 beacons cover Europe and the Eastern regions of Canada and the United States. The beacons are mutually coherent, being derived from a single oscillator source within the satellite which is duplicated to ensure long-term reliability. All other active items such as travelling-wave-tube amplifiers are also fully backed-up by redundant equipment.

Preparations for the Olympus Utilisation Programme

The earth segment

As is often the case with satellite systems, the user organisations tend to commit funds for the earth segment only when they are sure of the satellite launch date. This inevitably leads to an early post-launch phase where only a few earth stations are available. In the case of Olympus, therefore, the Agency has invested in a number of demonstration earth stations and associated equipment to provide a nucleus ground segment to be augmented by the users. A typical example is the TDS-5 earth station that provides the uplink for the European Direct Broadcast channel, currently located at Silwood Park near London (Fig. 5). There are currently 3 Broadcast uplink stations, 13 Specialised-Services stations and 28 stations for 30/20 GHz operation. In addition there are about 60 small stations used for micro-terminal systems and for propagation beacon reception and many thousands of TV receive stations.

The Olympus Utilisation Conference

The Olympus Utilisation Conference held at the new Austria Centre in Vienna, 12–14 April 1989, provided a forum for experimenters to discuss and reinforce their ideas on the use of Olympus.

The Conference, which was of great interest to engineers and managers concerned with the technical, commercial and educational uses of Olympus, was organised by ESA with the cooperative support of: Eutelsat, the Canadian Department of Communications, Telespazio, British Telecom, the Technical University of Graz, Politecnico di Milano, the

Figure 5. ESA's TDS-5 earth station at Silwood Park (UK), used for uplinking BBC television to Olympus

University of Surrey, Plymouth Polytechnic, the British National Space Centre, and the Technical University of Eindhoven.

Attended by more than 400 delegates from all parts of the World, the Conference was a great success. It provided the wider technical community with information about the satellite and its Utilisation Programme, thereby establishing sound channels of communication for the ensuing operational phases. The Proceedings of the Conference are available from ESA Publications Division (ESA SP-292).

An exhibition of equipment and information relevant to Olympus utilisation was held simultaneously. It included stands and exhibits from organisations in the aerospace and telecommunications fields.

General organisation

The Utilisation Programme is primarily designed to cater for those organisations wishing to experiment with new techniques and services which can later be transferred to commercial satellites. The payload capacity is in the first instance free-of-charge, but the Agency reserves the right to charge for experiments during the later phases of longer-running experiments where some commercial advantage becomes apparent.

Application for satellite time is made through the Olympus Payload Utilisation Secretariat (OPUS) at ESTEC in The Netherlands.

Many of the demonstrations and communications applications running on Olympus involve the Agency itself, either in organising the activity, in the loan of equipment, or in providing technical consultancy. The OPUS office has the task of encouraging use of the satellite for worthwhile purposes and to give as much technical and organisational help as possible within the resources available.

For experiments involving more than one European country, and which are in the field of public telecommunications, the Agency evaluates and agrees Olympus applications with Eutelsat. This is to ensure that the free capacity of Olympus is used to develop new services, rather than to bypass those already existing. This process has worked well and it has sometimes been possible to make a smooth transition from the experimental to the commercial environment.

Once a particular application is approved and a general schedule agreed, the allocation of day-to-day operating hours and the general control of access is handled by the Satellite Payload Operations Centre (SPOC) at Redu in Belgium. SPOC works under the guidance of the OPUS office and is available 24 hours per day for Olympus payload control activities.

The Utilisation Programme 1989-1990

By the autumn of 1989 all the elements were present; the satellite, the earth stations and a large and varied group of engineers, broadcasters and scientists. The Olympus Utilisation Programme could begin.

Broadcast Payload activities

BBC Television

On 14 June 1989 the Chief Executive of the British Broadcasting Corporation's BBC Enterprises Ltd. and ESA's Director of Telecommunication Programmes signed an agreement allocating the evening hours of the central European DBS channel capacity to BBC Enterprises. Since November 1989 the BBC has been broadcasting a mixture of BBC-1 and BBC-2 plus some special programmes to a potential European audience of several million viewers. The central Europe DBS channel transmissions of Olympus use the D2-MAC (Multiplexed Analogue Component) television system, as do the French satellite TDF-1 and the German TV-Sat. All three satellites are located at the same orbital position (19°W). The combined audience therefore has a choice of 12 TV channels on their very small domestic receiver installations.

The BBC Olympus share of the audience is still rather small but, in September 1990, BBC Enterprises launched a new service, 'the Enterprise Channel', to Europe via Olympus. This is being marketed as a complement to the other satellite services, providing an excellent range of choices for the European viewer. The BBC has identified a positive need among the public and cable companies in Europe for a news and current affairs service. It will also include a range of educational items such as health, language and travel. The BBC hopes to attract programmes from business and commercial organisations across Europe as well as other European broadcasters. Many programmes will carry subtitling or simultaneous translations in the main European languages, encouraging subscription, advertising and sponsorship.

Eurostep Television

Even before the Olympus launch, education by television or 'distance-learning' for both public, professional and corporate purposes was identified as a major interest among educational establishments, broadcasting organisations and companies. Encouraged by the Agency, a number of interested organisations combined together in 1989 to form the users' organisation, Eurostep (see ESA Bulletin no. 60, pp. 63-67). It currently has forty member organisations in twelve countries.

On 15 December 1989 ESA and Eurostep signed an agreement to allocate the necessary satellite capacity to enable Eurostep to make regular broadcasts via the central European DBS beam of Olympus. Two weeks later transmissions started on an experimental basis and in April 1990 the service was officially launched. It now provides nine hours of programmes per day on an extremely wide range of subjects and specialities. Operation since that time has in general been very successful and the service is building up a widely based international audience.

Eurostep uses the same transmission facilities as the BBC. The activities of the two organisations are therefore complementary and directed at the same potentially very large community of viewers with DBS receivers or cable connections.

ESA Television
Outside the times allocated to the BBC and Eurostep, the Agency itself has been providing information and general interest programmes using the European beam of Olympus. This has consisted of captions giving information about Olympus use and, from time-to-time, space-related films from the Agency's film library. The programme material is assembled at ESTEC in The Netherlands and transmitted via ESA's TMS-5 uplink broadcast earth station in Redu, Belgium.

RAI Television
The Direct Broadcast channel of Olympus, centred on Italy (Fig. 2) was assigned by the Agency to the Italian broadcasting organisation, RAI, 24 hours a day.

On Monday 29 January 1990, President Cossiga of Italy 'pushed the button' and, using Olympus, inaugurated the first RAI Direct Broadcasting Satellite channel.

RAI intends to develop direct broadcasting by satellite as an enterprise of strategic, industrial and cultural importance. The current experimental phase investigates different standards: television Phase-Alternate Line (PAL) and MAC transmissions, High-Definition Televison (HDTV), and high-quality radio transmissions, and also the impact of different technical services such as 'multi-audio' (broadcasting a programme and transmitting it in several languages through different audio channels), teletext transmission (including subtitles in different languages), data broadcasting (including telesoftware), video conferences, and the scrambling of video, and sound and data for conditional access.

An analysis of the programme demands will be determined by experimenting with the transmission of various types of programmes. These experiments will address not only demands in Italy (a large number of traditional terrestrial TV channels), but also those from abroad (Italians living in other countries and foreign spectators with varied interests).

On the occasion of the 1990 Worldcup in Italy, a demonstration of distribution via satellite throughout Europe of HDTV signals, using the HD-MAC emission system, was carried out jointly by the European Commission Project 'Eureka '95' and RAI. The HD-MAC transmissions covered the football matches played at the Stadio Olimpico in Rome, where the HD-MAC encoder was installed. In cooperation with the BBC, the HD-MAC signal was also transmitted on the Olympus European channel, thus covering most of Europe.

Further experiments of point-to-multipoint HDTV transmission signals via satellite were carried out using 'all digital' coders and decoders developed by Tettra SpA. The signals, generated by HDTV cameras in the various stadiums, were digitally encoded and transmitted at 70 Mbit/s to Olympus. The fixed up-link earth station located at the RAI Production Centre in Rome was used for the football matches played at the Stadio Olimpico in Rome, and a transportable up-link earth station was used for those played in other towns. The HDTV signals, from Olympus, were decoded and displayed to selected audiences on large screen projectors in a number of receiving sites in Italy, Spain, the United Kingdom and other European countries. The demonstrations received very favourable reactions from television specialists, managers and engineers throughout Europe.

Data transmission by television
A number of organisations are interested in addressing closed user groups using the

data transmission or 'datacast' capability of the Olympus MAC system. This is rather similar to the well-known 'Teletext' used in the PAL system, but with a much higher capacity of, on average, about 1 Mbit/s. Such a capacity is possible because the data is allocated a separate part of the line structure instead of being squeezed into the Vertical Blanking Interval (VBI) as in the PAL system. With these transmissions using the MAC format, it is also possible to address particular groups of receivers whilst excluding those to which the information is not applicable. The latter type of transmission is known as 'narrowcasting'.

British Telecom International (BTI) has been a pioneer in this area with an experiment in which the format to transmit TV and data to limited groups is being explored. BTI data narrowcasting was installed in Goonhilly in early December 1989. Test transmissions in full D-MAC commenced at the end of January 1990 and have included high-quality, linear-coded sound and narrowcasting data sent in the MAC/packet multiplex. First- and second-level protection, as defined by the European Broadcasting Union (EBU), have been used for error protection of the teletext data.

Amongst other users, Visnews of London has specialised news feeds which it wants to promote by transmitting them to any interested local broadcasters. A French-based venture is seeking to develop its existing national tele-shopping services to reach transnational markets across Europe. A new venture called Eurolynk is targeting the media trade with daily transmissions promoting programming available for commercial sale, as is currently done at various regular TV festivals and trade fairs. The Eurostep programmes include transmissions of both TV and courseware, the latter carried in the data part of the MAC signal, by individual companies and medical-interest groups and evolving towards the use of conditional access to protect their interests. The BBC are also experimenting with a datacast service 'Eurocast' using the VBI, for financial services and sports results, extending the datacast services in the United Kingdom.

Altogether, the Broadcast transponders are very busy except during the night and have an overall occupancy of about 60%.

Specialised-Services Payload activities

SS-TDMA

Two major Satellite-Switched Time-Division Multiple Access (SS-TDMA) experiments have started, using the onboard dynamic-switching capability of the Olympus Specialised-Services Payload. SS-TDMA enables the efficiency of satellite communications to be improved by directing messages destined for a particular location to narrow spot beams illuminating only the desired areas. This avoids wasteful illumination of unwanted areas, so reducing the cost of the traffic. The switching takes place onboard the satellite but has to be carefully synchronised and controlled from the ground.

The first experiment involves British Telecom, the Danish PTT and the Deutsche Bundespost. The first phase of the experiment deals with the development of the acquisition and synchronisation techniques at each of the earth stations to enable bursts of data to be passed through the satellite via the earth stations in a controlled manner. Test signals, including video conference signals for demonstration purposes, have been transmitted through the system.

Good progress is being made towards a fully synchronised three-part configuration covering Germany, Denmark and the United Kingdom. The next phase of the project will deal with interfacing the SS-TDMA equipment to existing public networks. In particular, it is envisaged that 'communication islands' containing high-density traffic associated with large conurbations will be linked together on an experimental basis using the Olympus SS-TDMA system.

The other SS-TDMA experiment is being conducted by the Technical University of Graz in Austria, the Italian National Research Council's CNR/CNUCE institute in Italy and Rutherford Appleton Laboratories in the United Kingdom. It aims to link together private, as distinct from public, local area networks using the SS-TDMA capability of the satellite. A programmable TDMA controller has been developed and built. Tests of this equipment have already been made using the ECS satellites and are now being continued on Olympus. At present only one station, at Graz, is being used. The experiment and the techniques are being tested on a loop-around basis using one beam of the satellite. It has been shown that, using the TDMA controller, it is possible accurately to synchronise to the on-board satellite switch and to pass information over the system. Demonstrations have been made between local area networks using computer-to-computer traffic, graphics and full duplex telephony at 64 Kbit/s rate.

The next phase of the experiment is to involve the other stations in the United Kingdom and Italy and to demonstrate a fully operational SS-TDMA system using the satellite switch.

Tele-education

Well before the launch of Olympus, discussions were taking place with Polytechnic South West in Plymouth (UK) concerning the feasibility of a tele-education broadcast service to schools, colleges and universities in the United Kingdom.

The Polytechnic has a fully equipped TV studio on the campus linked to a satellite operations centre. A transmitting earth station, the TDS-4B which is on loan from ESA, is being used to distribute educational television programmes (Fig. 6) to schools, colleges and universities within the UK. There is also a major project for the British Government's training agency in which three complete series of programmes on small businesses, specialist engineering topics and information technology are being transmitted to adult training centres.

One of the main features is that there is considerable emphasis on live, interactive programming with students at the remote receiving locations being able to participate by phoning in questions to a panel of experts in the studio. This aspect in particular has gone down extremely well with the students and gets over the 'canned video' flatness that is often associated with tele-education.

There are several hundred TVRO sites regularly receiving programmes from Plymouth. Some of these are on an informal basis, with the result that there is an ever-increasing number of enquiries about the programmes being transmitted.

High-energy physics

The international high-energy-physics organisation, CERN, in Geneva, have approached the Agency with a request to use Olympus for data distribution to remote scientific institutions not normally accessible through the public networks. The ground system for these applications is not yet ready, but the funding and organisation are certainly available and it is anticipated that CERN will be a major user of Specialised-Services Payload capacity by 1991.

Microterminal systems

In the United Kingdom a microterminal network has been developed by the British National Space Centre (BNSC) in association with Industry. A number of trials have taken place using the Specialised Services Payload to test the response time and throughput of the system under various traffic conditions. The hub station is at the Royal Signals Research Establishment (RSRE) at Defford and, at present, all the user terminals are in the United Kingdom only.

ESA has developed a microterminal system for applications in rural areas which uses very small earth stations, providing telephone connections in places where they are rare or non-existent. The stations are solar-powered and can be put in place very quickly. Demonstrations of this system will start shortly.

Figure 6. An educational broadcast in progress from Polytechnic South-West

General

Several Italian national experiments will soon be coming on stream as earth stations become available. Similarly Deutsche Bundespost will be expanding their use of the Payload shortly. Occupancy of the transponders is currently about 20%, which is reasonable in view of the tendency of most users to keep to 'office hours'.

Use of the 30/20 GHz Payload

Since the start of Olympus operations there has been considerable demand for this Payload. This is mainly because it operates in a new frequency band where there is considerable potential for future satellite communications capacity and where new techniques need to be developed to overcome the effects of the atmosphere, which are greater in these higher-frequency bands.

Tele-conferencing
One of the initial goals of the Olympus Programme was to provide capacity to experiment with new systems. At the start of the Olympus Development Programme, video conferencing was identified as a potentially important application. The Agency recognised, however, that, by the time Olympus was launched, a large number of video conference systems would already exist. It was therefore decided to concentrate the experiments in areas not previously addressed, including: simultaneous multiple-presence video conferencing, the use of fade countermeasures to minimise the effects of fading in the 30/20 GHz bands and the need to design a simple, easy-to-use, video-conference and business-communications environment.

Figure 7. A Direct Inter-establishment Communications Experiment (DICE) video conference in progress

With these objectives in mind the Agency has established a video-conference and business-communications experiment known as the Direct Inter-establishment Communications Experiment (DICE). The overall design of DICE has been carried out by the Agency with the assistance of the Polytechnic South-West (UK) as system consultants. Key developments have been undertaken by the Technical University of Graz under ESA contract, namely the video, sound and data units for the conference rooms and the special fade-countermeasure equipment which permits the use of 30/20 GHz by limiting the effects of fading in bad weather.

Testing of the overall complement of four earth stations, with associated video conference facilities and data communications modules, has been carried out at ESTEC using Olympus capacity. The system is now being deployed at Matra, (Toulouse, France), Marconi (Portsmouth, United Kingdom), British Aerospace (Stevenage, United Kingdom) and the Hispasat Office (Madrid, Spain). DICE will be used to facilitate informal daily contact between the members of the industrial team developing and producing Hispasat, the Spanish satellite to be launched in 1992. The time available for the development, manufacture and launch of Hispasat is very restrictive, so it is vital that communications are fast and effective. DICE is already demonstrating the advantages of simultaneous vision, sound and data between all participants (Fig. 7) and the efficacy of the 30/20 GHz frequency band in such applications.

Microterminal systems
For some time the Agency has appreciated the importance of communications systems based on Very-Small-Aperture Terminal (VSAT) earth stations. Use of these systems has increased dramatically in the United States and Japan in recent years and they are becoming increasingly relevant to the European scene as the telecommunications facilities are liberalised.

The most promising frequency band for the future growth of European VSAT systems is 30/20 GHz where plenty of bandwidth exists and no existing systems are operating. The Agency has used this opportunity to develop an experimental VSAT system, the Cooperative Olympus Data Experiment (CODE).

Designed by an international team from ESA, Technical University Graz, Polytechnic South West, British National Space Centre (BNSC), British Telecom and the University of Brussels, CODE provides communications between VSATs at 64 Kbit/s, via a hub station located at ESTEC in The Netherlands. It can support services such as electronic mail and data transfer. Database access, image transfer and remote printing can also be sustained using the hub station facilities. A basic nucleus of the CODE system is now established between five of the design group members. Further stations and applications are being added progressively. Each CODE VSAT terminal consists of an outdoor unit and a small indoor unit which connects to one or more personal computers via a standard ethernet Local Area Network cable.

Use of 30/20 GHz in Canada
The Olympus 30/20 GHz antenna beams have been directed towards Canada on a daily basis throughout most of the first year in-orbit. The Canadian Government's Communications Research Centre (CRC) in Ottawa is coordinating the Canadian experiments. These include business communications and satellite technology experiments.

A number of further projects are being planned which involve individual organisations in Canada cooperating with interested parties in Europe and in Africa. These include tele-education, tele-health and tele-seminar projects. They are expected to gather in pace and scope as the earth facilities become more readily available.

Internetworking
The Technical University of Graz in Austria have been active in the 30/20 GHz frequency band where they are conducting an internetworking experiment to link together local area networks. This system is based on the same basic technology as that employed in the SS-TDMA experiments on the Specialised-Services Payload. The emphasis, however, is on the use of fade countermeasures to ameliorate the effects of fading in the 30/20 GHz bands. A technique of slowing down the data rate and sending only essential information is employed.

Use of 30/20 GHz in Italy
In the forthcoming months there will be an influx of new experiments from the Italian PTT, Telespazio and various educational establishments such as the Politecnico di Milano and the Universities of Firenze and Torino.

One such experiment requiring simultaneous satellite access on the 30/20 GHz Payload and the Specialised-Services Payload will investigate development of reliable bandwidth switch-over procedures which will utilise the 12/14 GHz Ku band when a 30/20 GHz (Ka-band) link suffers severe attenuation due to propagation events. The target is to achieve a satellite communications link availability better than 99.99%.

There is also considerable interest throughout Europe in digital television broadcasting: a two-phase Italian experiment beginning in August 1990 investigates the transmission via Olympus of digital video signals at 30/20 GHz. The experiment will contribute to ongoing international studies of High-Definition Television (HDTV) by satellite.

A radiomobile coding experiment will evaluate the impairments that could arise in the telephone network due to connection with different transmission systems characterised by different amounts of delay.

Further experiments via Olympus are planned by the Italian PTT and other technical establishments involving point-to-point and point-to-multipoint video-conferencing, tele-education and development of a variable rate TDMA terminal. Forthcoming experiments include site and service diversity and synchronisation of remote atomic clocks for precise time measurements applied to satellite-ranging.

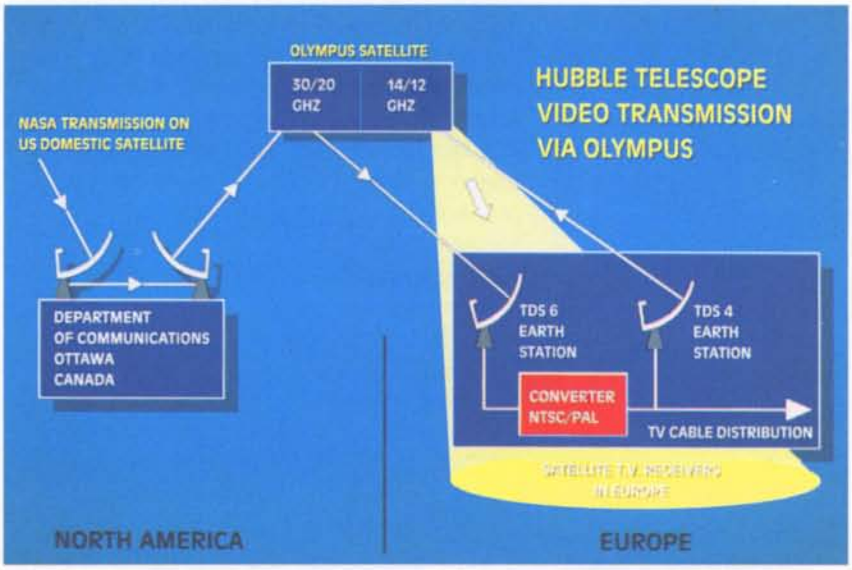

Figure 8. Arrangement of facilities for coverage of the Hubble Space Telescope launch

Use of 30/20 GHz in Germany
The Deutsche Bundespost have already completed a teleseminar experiment where video and sound distribution has been demonstrated to potential customers. In particular the effectiveness of distribution to very small earth terminals using 30/20 GHz was shown. Further experiments involving data distribution to microterminals, HDTV distribution via 30/20 GHz, and thin-route TDMA are planned.

The use of small 30/20 GHz uplink stations for TV news-gathering via satellite is also being explored. This technique looks very promising because the uplink stations potentially can be truly hand-portable in this frequency band, making it possible to receive news from reporters covering events throughout the world in a most flexible manner.

General
This payload is presently being used at approximately 30% of capacity. The occupancy is much higher during the working day.

The Italian and German experiments will shortly come into full operation as the various earth stations become available. The payload will therefore be heavily loaded for the foreseeable future.

Use of the Propagation Payload
There has been a very wide interest from scientific and educational establishments concerning the measurements of atmospheric attenuation and depolarisation using the beacons of Olympus. In particular the 30 GHz beacon provides the first opportunity to collect statistical information about this frequency band for many years. The fact that 30 GHz, 20 GHz and 12 GHz beacons co-exist on Olympus enables the propagation experts to correlate and calibrate earlier results taken with other satellites, thereby extrapolating them to the higher frequencies.

The experiments are co-ordinated by the Olympus Propagation Experimenters (OPEX) group. Within OPEX, subgroups have been established to deal with data-processing software evaluation, radiometry, attenuation, cross-polar discrimination, polarimetric 20 GHz measurements and radar measurements.

In virtually all of the ESA Member States and several other countries Olympus propagation experiments are being planned. Table 1 gives an overview of those already started or starting this year. At the majority of sites more than one beacon is received and radiometers are co-located to facilitate calibration of the results. Other measurements are planned in Raleigh, (USA), Madrid (Spain), some 20 more sites in Italy, two sites in Yugoslavia, in Spitzbergen (Norway) and a number of other places.

Table 1. OPEX measurement sites

Location (by Longitude)	Latitude deg/N	Longitude deg/E	Altitude m	Elevation deg
Blacksburg, VA (USA)	37.220	-80.450	400	13.4
Ottawa (CAN)	46.000	-76.000	200	13.5
Coventry (UK)	52.417	-1.517	100	27.8
Chilton (UK)	51.567	-1.283	100	28.6
Martlesham (UK)	52.060	1.286	25	27.5
Gometz la Ville (F)	48.671	2.121	170	30.3
La Folie Bessin (F)	48.653	2.196	160	30.3z
Delft (NL)	52.000	4.372	60	26.6
Leidschendam (NL)	52.092	4.389	8	26.6
Louvain (B)	50.667	4.617	160	27.6
Lessive (B)	50.130	5.150	162	27.9
Eindhoven (NL)	51.448	5.487	30	26.8
Turin (I)	45.067	7.667	238	32.0
Darmstadt (D)	49.869	8.625	180	26.9
Milano (I)	45.413	9.495	200	30.4
Kjeller (N)	59.983	11.033	20	17.4
Oberpfaffenhofen (D)	48.050	11.160	580	26.9
Munich (D)	48.189	11.629	514	26.6
Albertslund (DK)	55.680	12.360	30	20.6
Rome (I)	41.830	12.470	50	32.0
Graz (A)	47.068	15.495	289	25.7
Metsahovi (SF)	60.218	24.394	300	12.3

Demonstrations and special events
An unusual feature of Olympus is its wide range of payloads coupled with steerable antennas. Using these features it has been possible to show the capabilities of satellite telecommunications and broadcasting in quite a spectacular manner at a number of special events.

In March 1990 an organisation known as Focolare, which aims to spread the Catholic faith to young people throughout the World, was granted capacity on Olympus for a special festival held in Rome. The event involved many hundreds of participants and many dignitaries, including His Holiness The Pope. The Italian broadcasting organisation RAI uplinked the television programme of the event to the broadcast payload of Olympus. This broadcast was received directly by many homes in the southern and central parts of Europe. The ESA earth station complex in Redu, Belgium received the signal and retransmitted it to the central and northern parts of Europe through the Direct Broadcast European beam of Olympus. It was also possible to make a standard conversion in ESA from PAL to the North American TV system (NTSC) and to transmit the signal across the Atlantic to CRC in Canada using the 30/20 GHz beams of Olympus. From Canada the television event was further distributed in North and South America by existing commercial satellites. Using the flexibility of Olympus and the extensive ground segment available to ESA it was therefore possible to disseminate this event to many millions of homes worldwide.

In April 1990, Olympus was used to bring television coverage of the launch and deployment of the Hubble Space Telescope to Europe and to broadcast the event over the whole European, Scandinavian and North African areas (Fig. 8). The audience included many industrial companies whose teams of engineers had been involved in the development of the Telescope.

Numerous small events, involving a few hours of Olympus capacity, have also been covered (Table 2). The University of York in the United Kingdom held a course on the design and use of VSATs in April 1990. The Agency was able to send a special television message to the course participants and at the same time to demonstrate the use of VSATs with the Olympus Specialised-Services Payload. Figure 9 shows the pictures being received at York University, using a small indoor-mounted antenna loaned from Ferranti Communications.

Table 2: Some special events using Olympus in 1990

May	Transmission of the proceedings of the Basque regional conference on tele-education
June	Demonstration of the CODE system and Europe-wide broadcast of the Eurotelecom exhibition in Madrid
June	Demonstration of corporate-training for IBM Brussels to IBM centres throughout Europe
June	Broadcast of proceedings of a Spanish national conference in San Sebastian
September	Broadcasts to the International Broadcasting convention in Brighton (UK)
October	Broadcasting, CODE demonstration and video conference demonstrations at the International Astronautics Federation symposium in Dresden, East Germany

Figure 9. Demonstration using an indoor antenna at York University

The future

Olympus-1 contains a representative selection of payload elements which could form part of future communications satellites. For the purposes of the Utilisation Programme, which is essentially experimental in nature, it provides an extremely diverse and flexible capability, which would not be available or needed in a standard commercial satellite. It has considerable capacity in three important frequency bands, Broadcast, Specialised-Services and 30/20 GHz, and provides many unique features such as beam-steering of all the antennas to give extensive coverage flexibility and onboard dynamic satellite-switching. The Development Programme for the satellite included the construction of several earth stations, which have been used as the catalyst to start the Utilisation Programme.

In the Broadcast area there is no doubt that we can foresee a considerable expansion of the quality and content of BBC activities with the development of the Enterprise Channel. In the field of distance-learning Eurostep has already made a very good start which will be built on in 1991 and beyond. Given the wide support and encouragement it has received from all parts of Europe, Eurostep's future seems assured. The Raisat television channel will surely increase its audience and programme content, and it seems likely that high-definition television will be a major feature of these transmissions in the future.

With new satellites there tends to be a time-lag in the development of the earth segment. In the Olympus case there are some potentially very-large-capacity users who are now nearly ready to use the satellite. Deutsche Bundespost, in particular, have a number of experiments scheduled to use Olympus 30/20 GHz and Specialised Services capacity in 1991. Similarly the Italian telecommunications organisation Telespazio have a number of earth stations which are now coming into service. This will permit organisations such as the Politecnico di Milano, Fondazione Ugo Bordoni (FUB) and others to use Olympus in the coming years.

The demand of the 30/20 GHz payload capacity has been considerable and there is a great deal of further interest which will ensure its full use in the future.

Following the successful launch and in-orbit testing of the satellite, the Utilisation Programme has grown steadily in activity and diversity. Many countries and within them many organisations, ranging in size from local schools to major industrial corporations, are now using Olympus capacity. As a result of the experimental transmissions made possible by the Utilisation Programme, new services and techniques in the sphere of satellite communications and broadcasting are being developed to satisfy the needs of the future.

The 'PAX' Experiment on Olympus

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The Olympus telecommunications spacecraft carries an ultrasensitive accelerometer package – known as the PSDE Accelerometer Experiment, or 'PAX' – designed to measure the minute disturbances caused by the operation of onboard equipment. This novel data has been used to study the operating environment that will be experienced by a highly sensitive laser-based communications package called 'Silex' to be flown on a future ESA spacecraft as part of the Agency's Payload and Spacecraft Development and Experimentation (PSDE) Programme.

Introduction

The primary purpose of PAX is to measure the in-orbit behaviour of a typical telecommunications satellite's structure in order to obtain design data for the Silex PSDE optical payload, which will have a very demanding pointing accuracy (about 0.3 μrad).

A secondary purpose of PAX is to monitor the different mechanisms on board Olympus (Fig. 1) at intervals throughout their lifetime in order to detect trends in performance. This technique has been used, for example, in the monitoring of helicopter gearboxes, but this is the first time that a facility to perform such monitoring on a spacecraft in geostationary orbit has been flown.

The transmission of low-amplitude, high-frequency vibration through spacecraft structures has never previously been critical to a telecommunications payload. Some in-orbit measurements made on Landsat-4 were published in 1984, but they were limited at 125 Hz. Knowledge of the higher frequency micro-vibrations that occur is critical to the design of the Silex tracking control loop and such was the concern regarding the potential microgravity environment that in July 1987 the possibility of in-orbit measurements was considered. The earliest flight opportunity thereafter was on the Olympus F1 spacecraft.

It was known that Matra had produced a microgravity experiment package that was about to be flown on a Chinese spacecraft. That flight was planned to last just five days, after which the satellite was to be de-orbited and the experiment data analysed on the ground. The Matra package contained four accelerometers with a sensitivity of 5 μg for the frequency range 2.2–11.5 Hz, with data limited to what could be stored in five 64 K solid-state RAM devices.

Discussions with Matra led to the conclusion that their existing package could be redesigned to meet ESA's requirements, with the frequency range being extended to 0.5–1000 Hz (which placed severe constraints on the structure and packaging of the assembly) and the data being transmitted in real time via one of the Olympus payloads.

Table 1. PAX Equipment Specifications

Mass	2.37 kg
Power consumption	6.3 W (normal) 0.3 W (standby)
Current	125 mA (normal) 6.2 mA (standby)
Dimensions	200 mm long 134 mm wide 110 mm high
Operating temperatures	+80°C maximum −20°C minimum
Minimum eigenfrequency	1000 Hz
Frequency bandwidth	0.5—1000 Hz
Sensitivity	±100 mg coarse mode ±10 mg fine mode
Resolution	50 μg coarse mode 5 μg fine mode

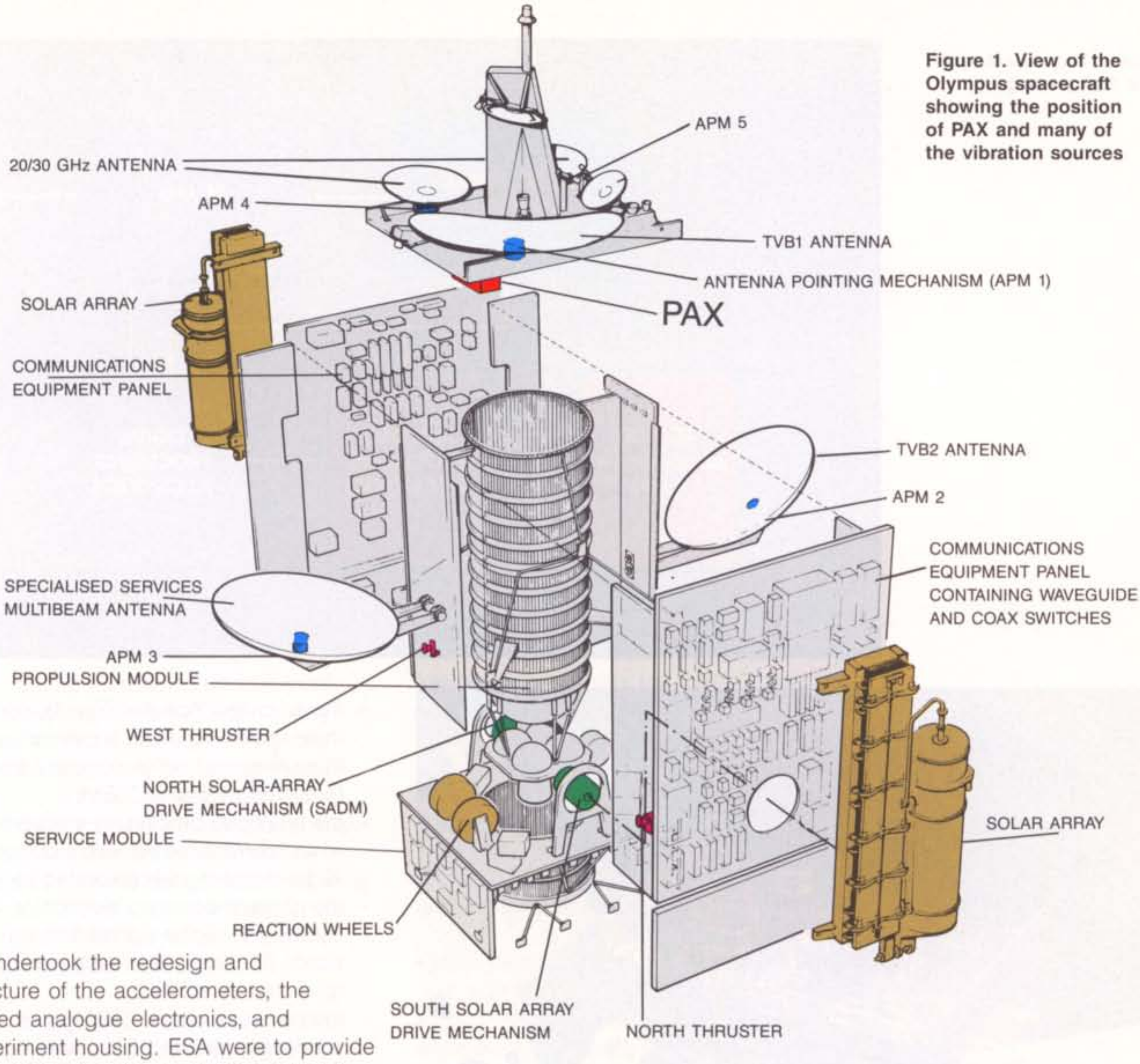


Figure 1. View of the Olympus spacecraft showing the position of PAX and many of the vibration sources

Matra undertook the redesign and manufacture of the accelerometers, the associated analogue electronics, and the experiment housing. ESA were to provide the power supplies, the analogue-to-digital conversion and the radio-frequency input circuitry. A modular design was adopted to permit parallel development of critical circuits and thus reduce schedule impacts in the event of problems.

Hardware manufacture

Development of the three different items of electronics was started at ESTEC just one month later, at the end of August 1987, and a feasibility study was completed by the end of September. Detail design and manufacturing were completed by the end of December.

The Matra work, which ran in parallel with this, was on an equally tight schedule, combined with a very low budget. Their programme was kicked off in mid-October 1987 and the initial design and manufacturing of the mechanical and analogue-electrical components took until mid-December.

The PAX flight hardware consists of a single box containing five elements (Figs. 2 & 3). These elements are:

Figure 2. The PAX flight unit (courtesy Matra)

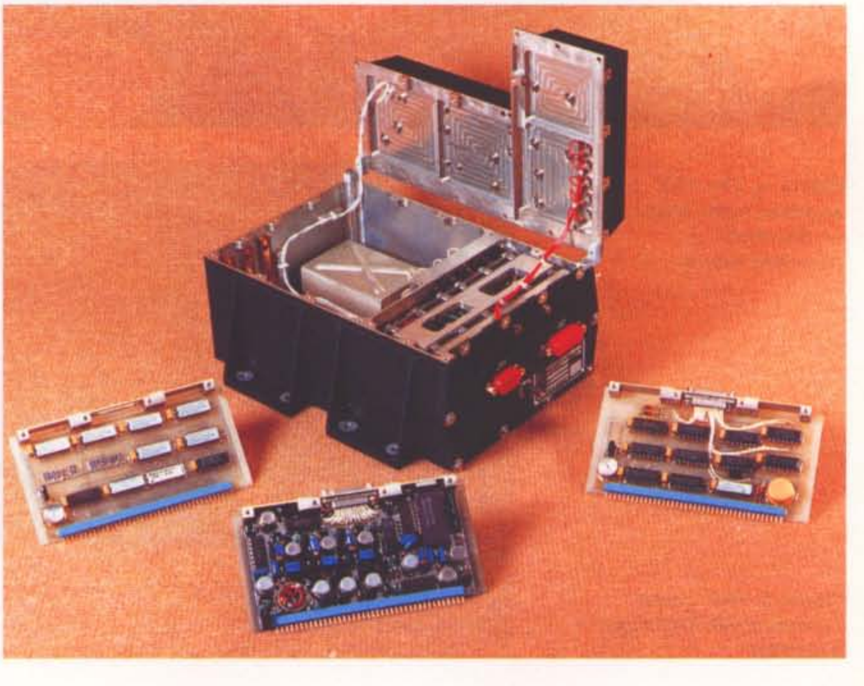
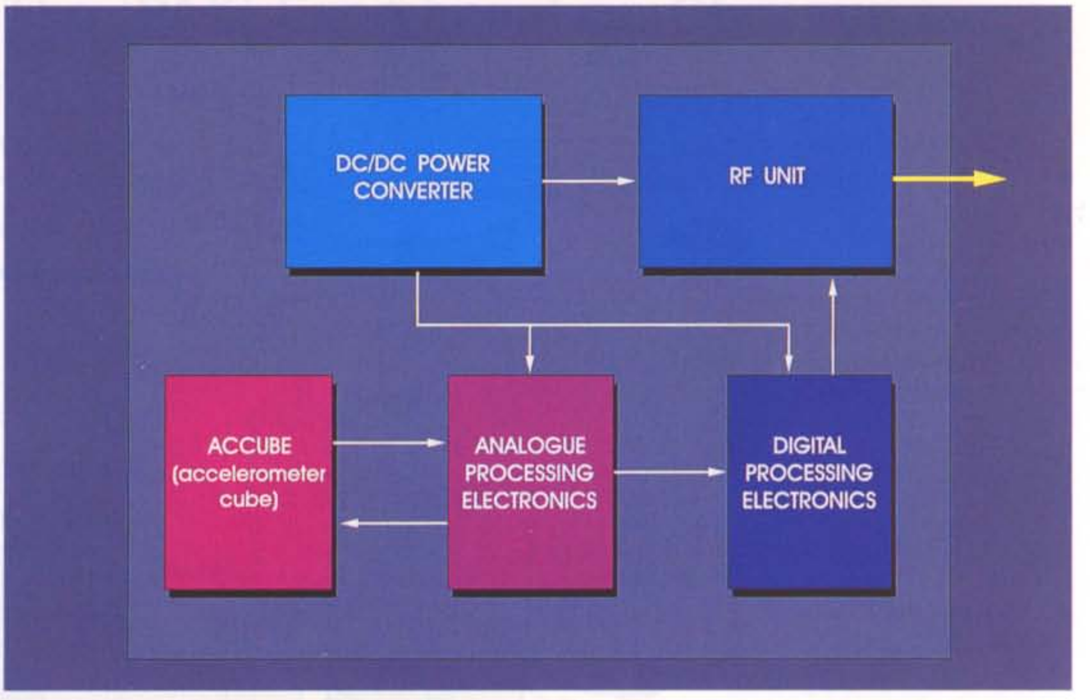
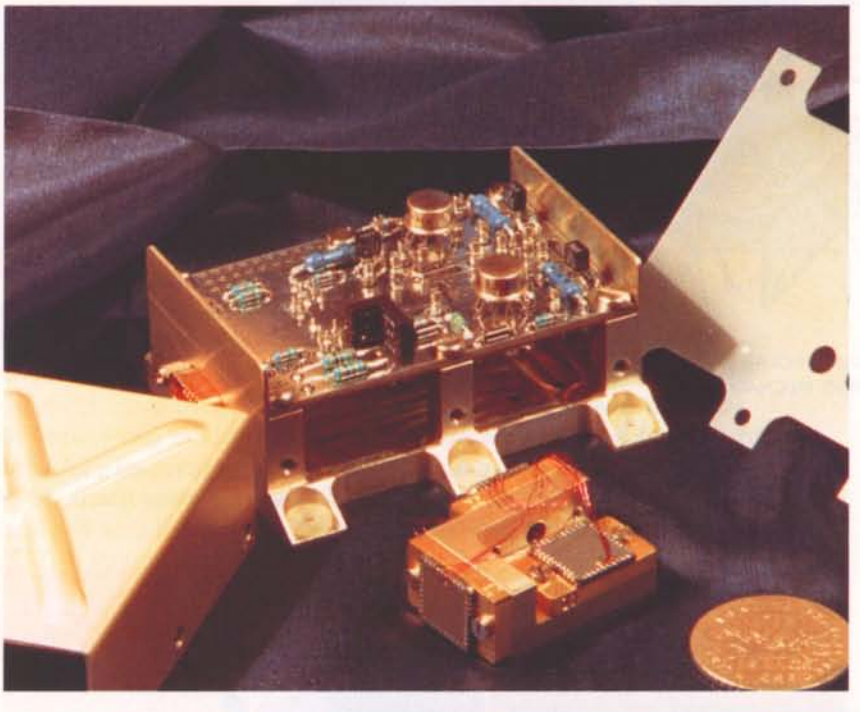


Figure 3. The constituents of the PAX package





- the so-called 'Accube' (Fig. 4), containing three accelerometers, a calibration thermistor, and some proximity electronics (provided by Matra/CSEM)
- the analogue processing electronics, which convert the Accube's outputs into 12 bit digital signals (provided by Matra)
- the digital processing electronics, which convert the digital signals into serial data words (80 bit) for telemetry purposes (provided by ESTEC)
- the power converter (DC/DC), which interfaces with the 50 V power bus and provides six regulated voltages within the PAX (Fig. 5). It also contains redundant on/off relays and generates a telemetry status signal (provided by ESTEC)
- the radio-frequency (RF) unit, which generates a carrier signal (12.1 GHz) modulated by the serial digital data (provided by ESTEC).

Figure 4. The PAX accelerometer assembly, or 'Accube' (courtesy Matra)

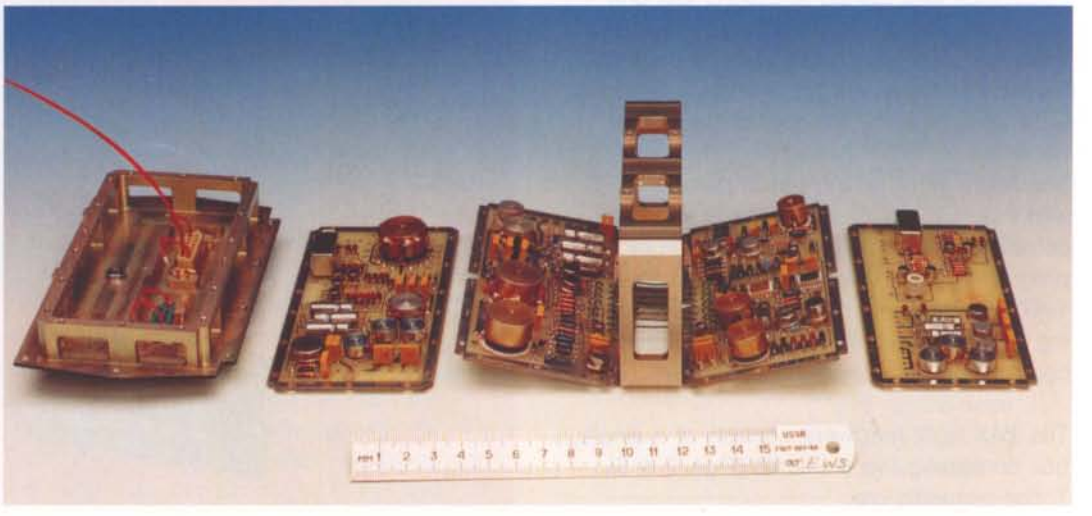


Figure 5. PAX power converter (DC/DC) flight hardware

The three accelerometers, one for each of the spacecraft's three degrees of freedom, are so-called 'gas-damped cantilever units' manufactured by CSEM (Centre Suisse d'Electronique et de Micro-electronic) in Neuchâtel, Switzerland. The inertial mass is a rectangular plate (2 x 3 x 0.37 mm) weighing 0.0052 gm, supported by a cantilever (1 mm x 2 mm and 1.4 μm thick). Each accelerometer is contained in an hermetically sealed case. The unit's output is the variation in capacitance produced by movement of the mass between electrodes.

The complete Accube assembly, which also includes a thermistor and a small printed-circuit board carrying the proximity electronics, weighs just 150 gm and has a fundamental resonant frequency above 1.5 kHz.

The fact that the hardware's development and manufacturing schedule was so very tight does not mean that it was free from development problems. Two of the most critical were the hermetic sealing of the accelerometers and the resonant frequency of the assembly. The first was solved by changing both the adhesive used for sealing the cover to the base, and the material of the base itself. The second was cured by modifying the equipment box.

Whilst the design and manufacture of the PAX hardware was proceeding, many other problems also had to be dealt with, such as telecommunications-channel usage, radio-frequency link-budget calculations, ground-station design and procurement, preparation of data-handling software and, last but not least, the impact of PAX's inclusion on the Olympus Programme itself.

Calculations had shown that if PAX data were transmitted at low power there would be no interference with the Italian TV channel normally transmitted on Olympus' TVB1 beam. In January 1988 a laboratory test was performed which successfully verified this conclusion. Even so, PAX was intended to be used only for limited periods at intervals during the satellite's lifetime.

The modifications necessary to Olympus itself to incorporate PAX included electrical-harness modifications, provision of a mechanical interface, thermal-control changes, changes in mass properties, changes to the telemetry and telecommand system, and changes in payload software. The overall cost of these changes was comparable to that of the PAX hardware itself.

Ground equipment

The ground electronics were designed and manufactured at ESTEC and are linked to a commercial work station for data storage and analysis. Data-handling software was developed by CARA Data Processing Ltd., in Dublin (Ireland), with the assistance of the Institute of Sound and Vibration Research (ISVR), at Southampton University (UK). This software performs two basic functions, data acquisition and data analysis. Every data file is uniquely identified and can thus be directly related to events on the spacecraft. The analysis module produces amplitude/time or amplitude/frequency plots for data blocks of 0.3 to 600 s.

Ground testing

The Olympus spacecraft was already fully integrated and under test in the Canadian Government's David Florida Laboratory in Ottawa (Canada) when the PAX Programme was conceived. The last thing that the project needed was an experimental unit thrust upon them in the midst of their test programme. Hence the most critical consideration in the PAX qualification programme was the safety of the Olympus mission.

Firstly, therefore, an engineering-model PAX unit, built to flight standard but containing a dummy Accube, was tested to the Olympus-equipment qualification environment. Subsequently, the flight-model PAX was acceptance-tested to Olympus-equipment requirements and, after a test review at ESTEC, was integrated into the satellite, where it underwent system-level environmental testing. The unit is mounted on the lower side of the Earth-facing (+z) platform (Fig. 1).

Tests were made to evaluate the low-level vibration characteristics of the Olympus flight-integrated spacecraft and to calibrate the PAX equipment. Accelerometers were attached to a number of points on the structure and a 'calibrated hammer' was used to introduce a shock spectrum at specific points, such as thruster attachment brackets.

Such measurements made on the ground differ from those in orbit in two ways. On the ground there is always background noise present from the vibration of nearby equipment, footsteps, traffic in the street, or electrical pickup. None of this will be present in space. Also, on the ground there is air damping on all elements of the spacecraft structure. These two effects tend to mask and reduce the levels of transmitted vibration.

In-orbit testing

Because the PAX data is transmitted via the TVB1 payload, it was not available during the satellite's launch or during the deployment of its solar array and antenna. PAX was in fact switched on some weeks after launch and the first test recordings were made on 10 August last year.

During the very early stages of testing the PAX ground station, the analogue output was fed into a spectrum analyser, which gave immediate confirmation that the system was functioning correctly. The signal was also recorded on tape and played simultaneously

position had small leading edge overshoot spikes over part of the wave form, and this was causing a 'ringing' in the motor).

This early period of operation was used largely to commission the PAX ground equipment and to become conversant with the operational techniques required to obtain test data. In order to be able to monitor spacecraft status with minimum disturbance to the Olympus controllers at ESOC, use was made of the Multi-Satellite Support System (MSSS) and Communications Satellite Monitoring Facility (CSMF) terminals in ESTEC, which provide real-time displays of selected spacecraft parameters. Eventually, a special PAX display screen was generated using ETOL (European Test Operations Language) for use with the CSMF terminal (Fig. 6).

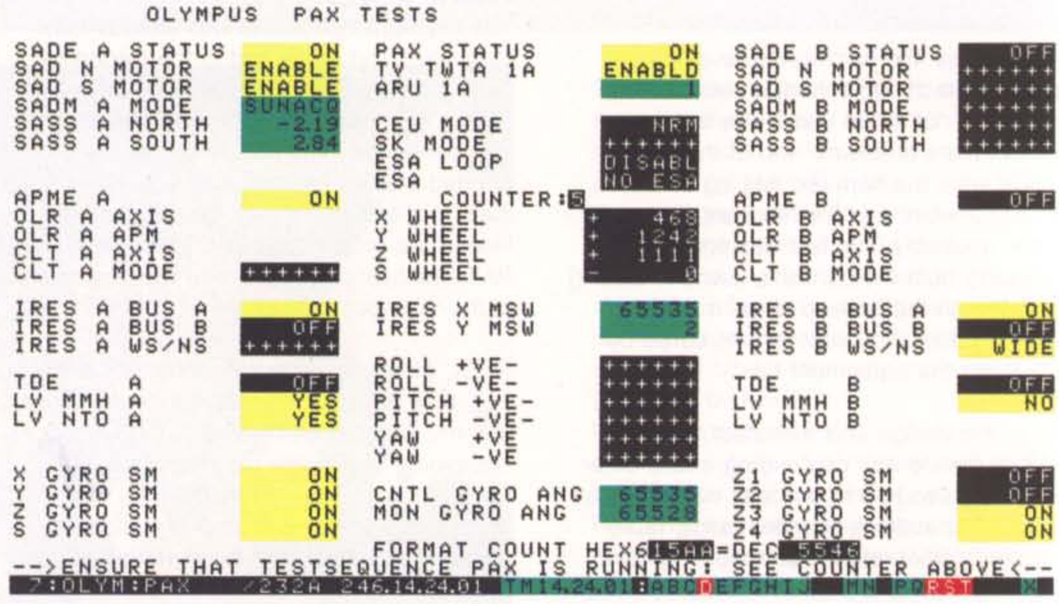


Figure 6. PAX data screen on the CSMF terminal

in real time through a loudspeaker. The latter was a revelation in that every mechanical event on Olympus could be heard as if with a stethoscope.

The first, unexpected, observation was a repetitive noise with irregular characteristics. The sound came in groups of three or four bursts about 450 ms apart, repeating about every 14 s. The source was identified by changing the stepping speed of the solar-array drive mechanism (SADM) and noting that the sound characteristic also changed. The result of this test was relayed to the spacecraft controllers in ESOC in Darmstadt (D) by the simple expedient of holding a telephone handset close to the PAX loud-speaker. Subsequently, the cause of the noise was traced to the mini-stepping electronics of the SADM motors (the digitised sine wave used to control the motor's

The initial link-budget calculations had indicated that it would be possible to use a 1.2 m dish at ESTEC (loaned by the ESTEC Satellite TV Hobby Club) for the ground station, but in practice the strength of the received signal was found to be marginal. Hence the PAX ground station and CSMF terminal were later moved to the Satellite Communications Building at ESTEC and connected to the TDS-5 Transportable Ground Station. This has a 4 m antenna which provides sufficient output to give a reliably clear signal even under unfavourable weather conditions. The remainder of the PAX testing was conducted with this setup.

Initially data was collected whilst Olympus was being worked up to operational status, but it sometimes proved difficult to conduct PAX runs without disrupting spacecraft operations at ESOC and at the Redu ground station in Belgium. Eventually, therefore, it was agreed to devote a period of time specifically to PAX tests. This proved to be a great success, with virtually every device on the spacecraft being operated in turn and its effects recorded.

One of the more difficult tests to organise was one required to establish the background noise contributed by the digitising within the PAX itself, which ideally requires a perfectly silent spacecraft with all systems off. There was some reluctance to provide this as it implied total loss of all attitude and orbit control functions, and so a 'minimum-noise state' during a spacecraft north-south station-keeping manoeuvre was used. The reaction wheels were stopped and only the infrared earth sensor, gyroscopes and thrusters were operating. The minimum-noise condition that resulted was punctuated by the staccato rattle of thrusters maintaining spacecraft pointing stability, but analyses could be made between thruster firings.

When the spacecraft testing was complete, Olympus operations were handed over to Telespazio at the Fucino station, in Italy, and the TVB1 antenna was repointed to Italy, where it is used for direct TV broadcasting. It is still possible, however, to monitor the PAX output by using a 9 m antenna at Redu.

Results

A total of 8 h of data were collected, varying from tests lasting a few seconds to full runs of 10 min each. The task of plotting these data in a form suitable for initial quick-look examination was undertaken by ESTEC Test Division and resulted in a dossier of about 1050 plots covering all recorded data (examples are shown in Figs. 7 & 8).

For each of the PAX runs, it was necessary to log details of the spacecraft's status during the relevant time periods. For every run, therefore, there is a summary sheet indicating spacecraft status and operations. After the timeline plots had been produced in ESTEC, a further contract was placed with CARA to produce more detailed plots for specific cases of interest, but so far it has only been possible to process about 20% of the data recorded. This has highlighted the urgent need for the development of statistical techniques for dealing with the much larger quantities of data that will be available in the future.

A summary of the typical amplitude results obtained is given in Table 2.

Guidance with the analysis has been provided by ISVR. This institute has been extensively involved in the measurement and

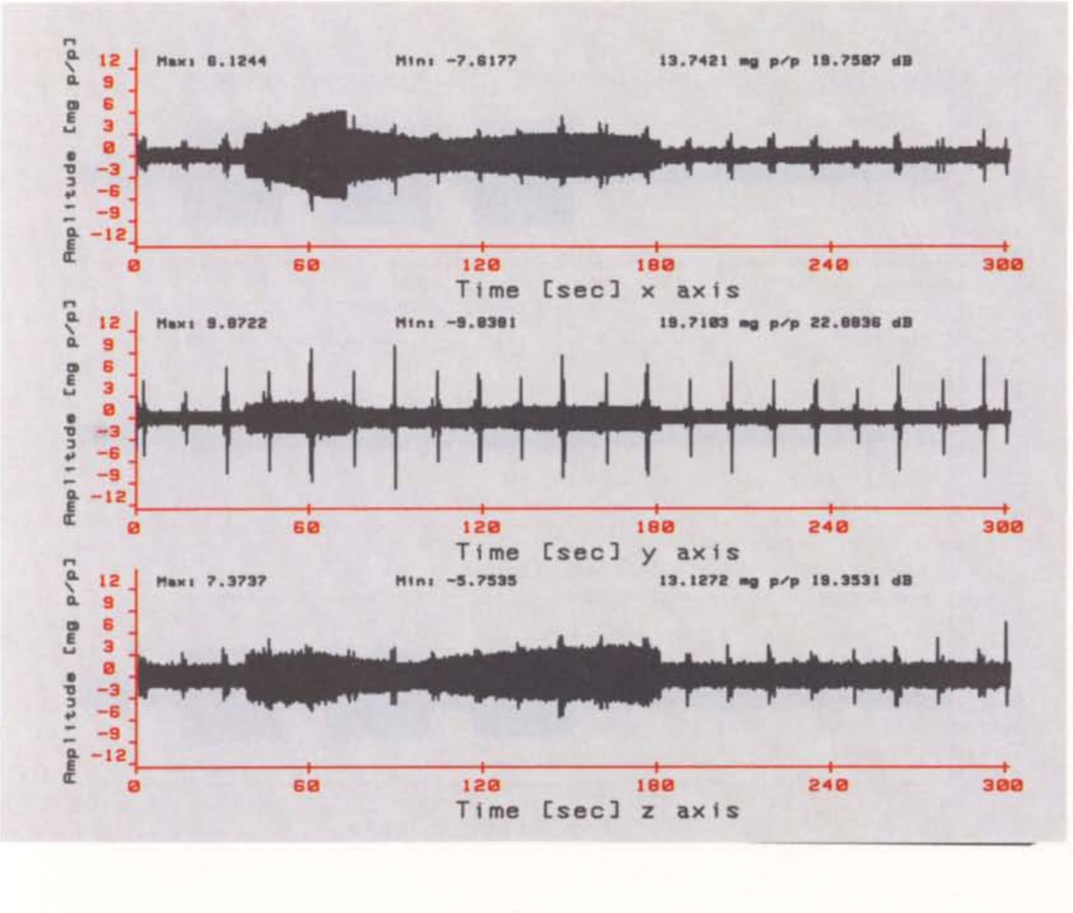


Figure 7. Typical PAX time-domain plot. This run lasted 5 min and all three accelerometer outputs are plotted in parallel

The events repeated at approx. 14 s intervals are caused by the SADMs, and have maximum intensities of about 10 mg. The background noise of approx. 1.5 mg is caused mainly by the spacecraft's reaction wheels. At 37.5 s, an APM was commanded to its zero position. At 70 s, one APM motor reached its zero position and stopped, while the other continued to run until 182 s, which represents almost a full rotation of the APM axis

Table 2. Typical acceleration levels measured by PAX

Event	Typical peak amplitudes, mg X-axis	Y-axis	Z-axis
Background	0.6	0.6	1.0
Thruster	32.0	36.0	52.0
Solar Array Drive Mechanism (SADM)	3.6	6.0	4.8
Waveguide Switch	28.0	100.0	75.0
Antenna Pointing Mechanism (APM)	3.0	1.0	2.5

prediction of structural transfer characteristics and were able to bring their skills to bear on the PAX problems using, for example, techniques developed for speech analysis.

As mentioned earlier, it was found that merely listening to the audio output of the PAX analogue signal proved very informative about spacecraft functions. The regular sound of SADM stepping, the noise of a

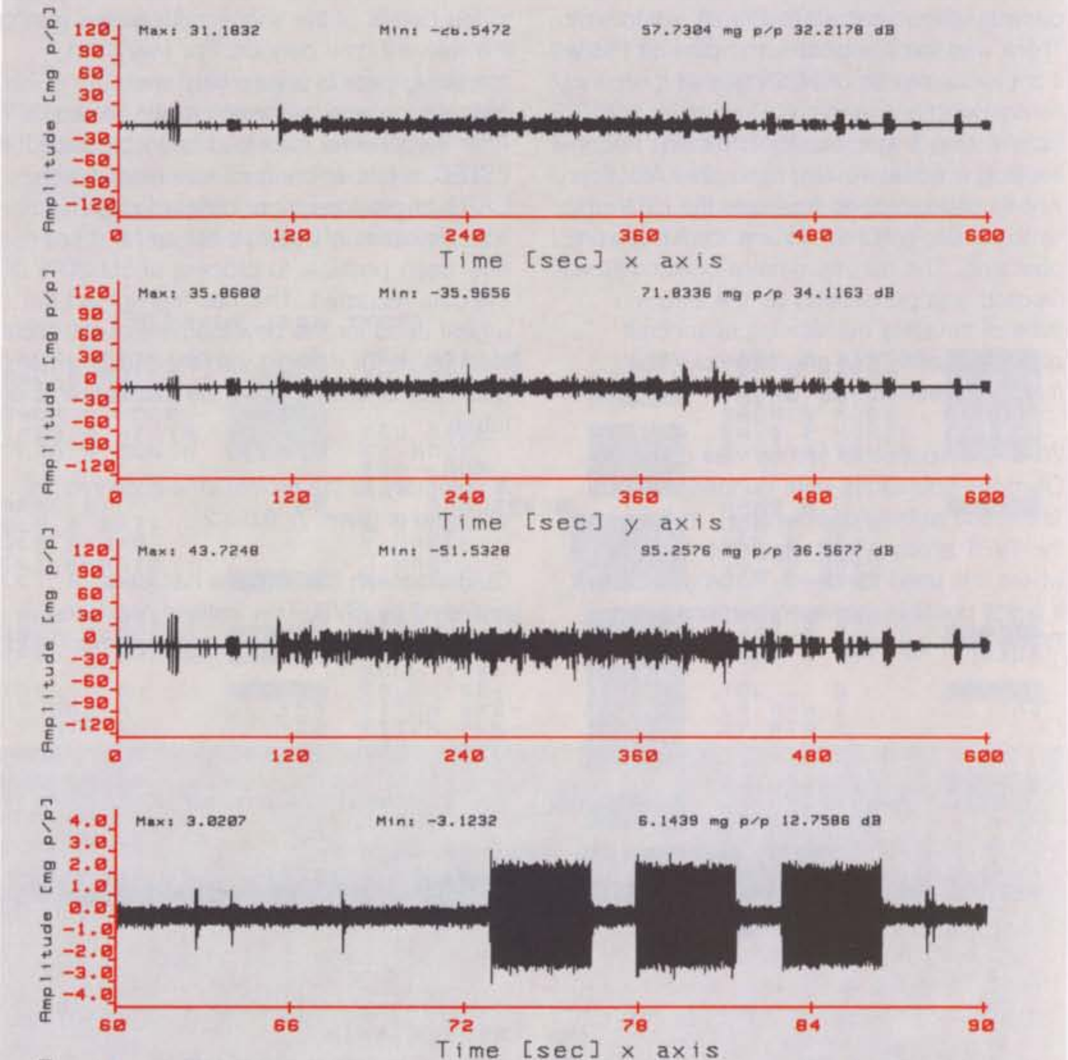


Figure 8a. Three-axis timeline plot of a 10 min PAX data file, showing a 5 min east/west station-keeping thruster firing and numerous other control-thruster firings

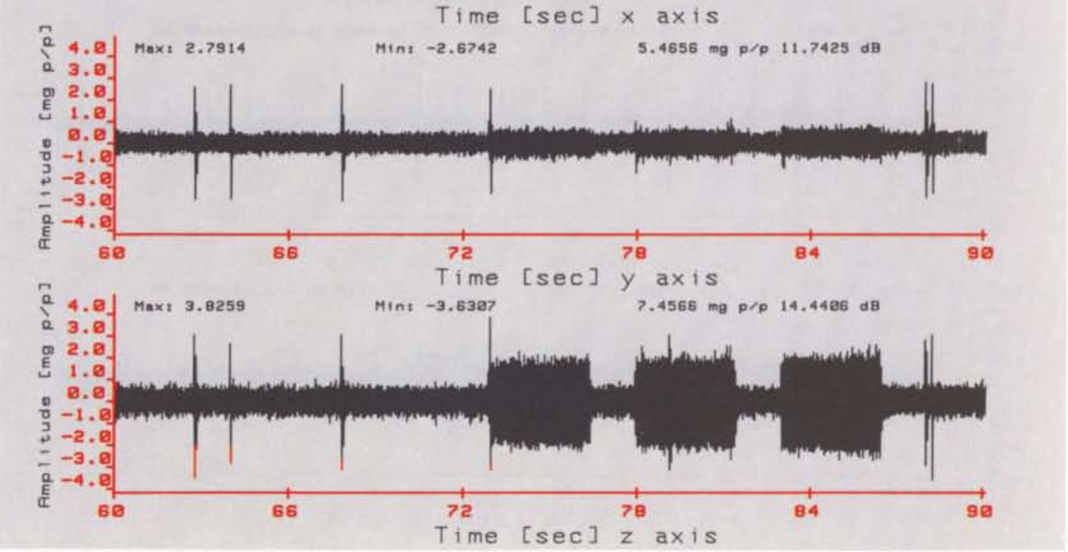


Figure 8b. 30s timeline plot showing normal stepping of one APM axis with blocks of 511 steps repeated at 5 s intervals, the first occurring after 73 s

thruster firing, or the crack of a waveguide switch closing were easily recognisable. The sound of an antenna pointing mechanism stepping, and even its location on the spacecraft, could be readily identifed.

It became apparent during the early operation of PAX that there were vibration sources that had either not been expected or were of greater significance than expected. One such example is the repetitive SADM noise which, although in no way detrimental to Olympus' operation, could be significant to any future laser-based communications package. The same is true of the operation of waveguide switches, which causes as much disturbance as the firing of a thruster.

Equipment to be flown on future spacecraft with microgravity-sensitive payloads should be characterised against a standard test rig. The data derived from this characterisation can then be used in conjunction with the transmission characteristics of a structure to predict the in-orbit vibration environment. The same data can also be used to assist with the analysis of PAX data returned from orbit.

Future PAX development and flights

So far, the audio data have been recorded completely independently of the PAX digital data and there can be no correlation between the two. It is, however, intended to construct a digital-to-analogue converter so that the digitally stored PAX data, which is fully documented and plotted, can be read out to audio tape. It is hoped that this will lead to improved techniques for handling the much larger quantities of data that will become available in the future.

The present data-collection method requires continuous interaction between the PAX operators and the spacecraft controllers, which introduces an unnecessary complication. In future PAX data will be collected using a special recorder that can store 24 h of PAX output on one 8 mm videotape. With access to the spacecraft command history files and a suitable time base on the tape, the impact on routine spacecraft operations will be minimal.

The ease with which such large quantities of PAX data can be stored (2.3 Gbyte every 24 h) introduces its own problems. One of the principal lessons learned is that the data-analysis technique has to be fully automated. The technique currently envisaged is an initial scan of the recorded data using a combination of audio and analogue display, in combination with the command history file or known test plan, to identify the principal events such as thruster firings, switch operations, etc. Once these events have been 'finger-printed', the data must be scanned by computer to produce a statistical probability of the occurrence of each type of disturbance, together with an average and worst-case vibration characteristic.

Further flights of PAX accelerometers are planned in order to measure the high-frequency vibration environment on a range of spacecraft structures. In future PAX will also have its own Ku-band transmission system so as to be independent of the spacecraft payload. In some cases it is intended to fly multiple accelerometer packages and to attempt, by means of the phase difference between the outputs, to measure the rotational displacement between positions on the structure.

Possible PAX launches presently under discussion include flights on the Lockstar-F2 (1992/3), Italsat-F2 (1993), Artemis (1994) and Spot-4 (1994) spacecraft.

Conclusion

The PAX experiment on Olympus has been a very successful low-cost programme. A considerable amount of analysis remains to be done on the first batch of data and on that which will be obtained from the future flights. The PAX experiment is not seen as an end in itself, but as the start of an area of work that will increase our knowledge of space structures and the dynamics of vibration transmission in orbit.

Extension of the ESTEC Test Centre

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The setting up of a European Integrated Test Centre at ESTEC for Ariane-4 class satellites has involved the provision of a new Test Preparation Area, a Large European Acoustic Facility, and a Compact Payload Test Range. With these new test facilities on stream and the space simulation and vibration facilities that were already available, it is now possible to perform all major space-environment testing literally 'under one roof' at ESTEC.

The new facilities are compatible with the test requirements for the majority of the large elements and structures that will be built in the coming years for Europe's Columbus, Hermes and Ariane-5 Programmes.

Introduction

The new items described here were necessary to complement those approved and built as part of the Agency's earlier investment in such facilities at ESTEC, namely the Large Space Simulator (LSS), the electrodynamic Multi-Shaker System (MSS), and the large test preparation area. A review of these facilities was published in ESA Bulletin No. 38, in May 1984.

The rationale behind these latest investments takes into account the fact that adequate facilities for testing medium-sized spacecraft are already available at CNES/Intespace in Toulouse (France) and IABG near Munich (Germany), and that facilities being installed at ESTEC should therefore be geared specifically to Europe's future large spacecraft.

The final 'go-ahead' for the new facilities, which was somewhat delayed in order to incorporate the latest requirements for the Hermes, Ariane-5 and Columbus Programmes, was given early in 1987. The major procurement contracts with industry, totalling 17 Million Accounting Units at 1988/9 prices, were placed at the end of that same year.

The new facilities were formally inaugurated by Her Majesty Queen Beatrix of The Netherlands, accompanied by His Royal Highness Prince Johan Friso, on 29 June 1990 (see ESA Bulletin No. 63, pp. 82–85).

The Integrated Test Centre concept

As can be seen from Figures 1 and 2, the new facilities are a logical extension of the existing building complex, with the overriding goal of forming an 'Integrated Test Centre'. The latter has been designed in such a way that all tests can be performed literally 'under one roof', allowing spacecraft to be moved smoothly from one facility to another, minimising the risk of damage during handling, allowing the shortest possible test schedules, and providing the greatest flexibility for testing and retesting in the event of problems or failures. This concept of having an integrated facility has often been shown by experience to bring substantial benefits, particularly for system-level testing.

The dimensions of all new facilities and buildings are compatible with the large elements of the Agency's Columbus, Hermes and Ariane-5 programmes. In this context a special study has been made to ensure that the hardware to be tested for these large programmes can be transported to and from ESTEC by air, water and road, as appropriate, without difficulty.

Aside from the large test facilities themselves, provisions have been made for associated supporting elements such as additional check-out rooms, office and meeting areas to accommodate two customer teams of 45 persons each, simultaneously. An additional 500 m^2 storage area is available for hardware containers/carriers during test campaigns.

Once at ESTEC, the large items for test will be admitted through the new airlock (1), which has a separate bridge crane for off-loading. Via the transport bay (2), the hardware can then enter the new Test

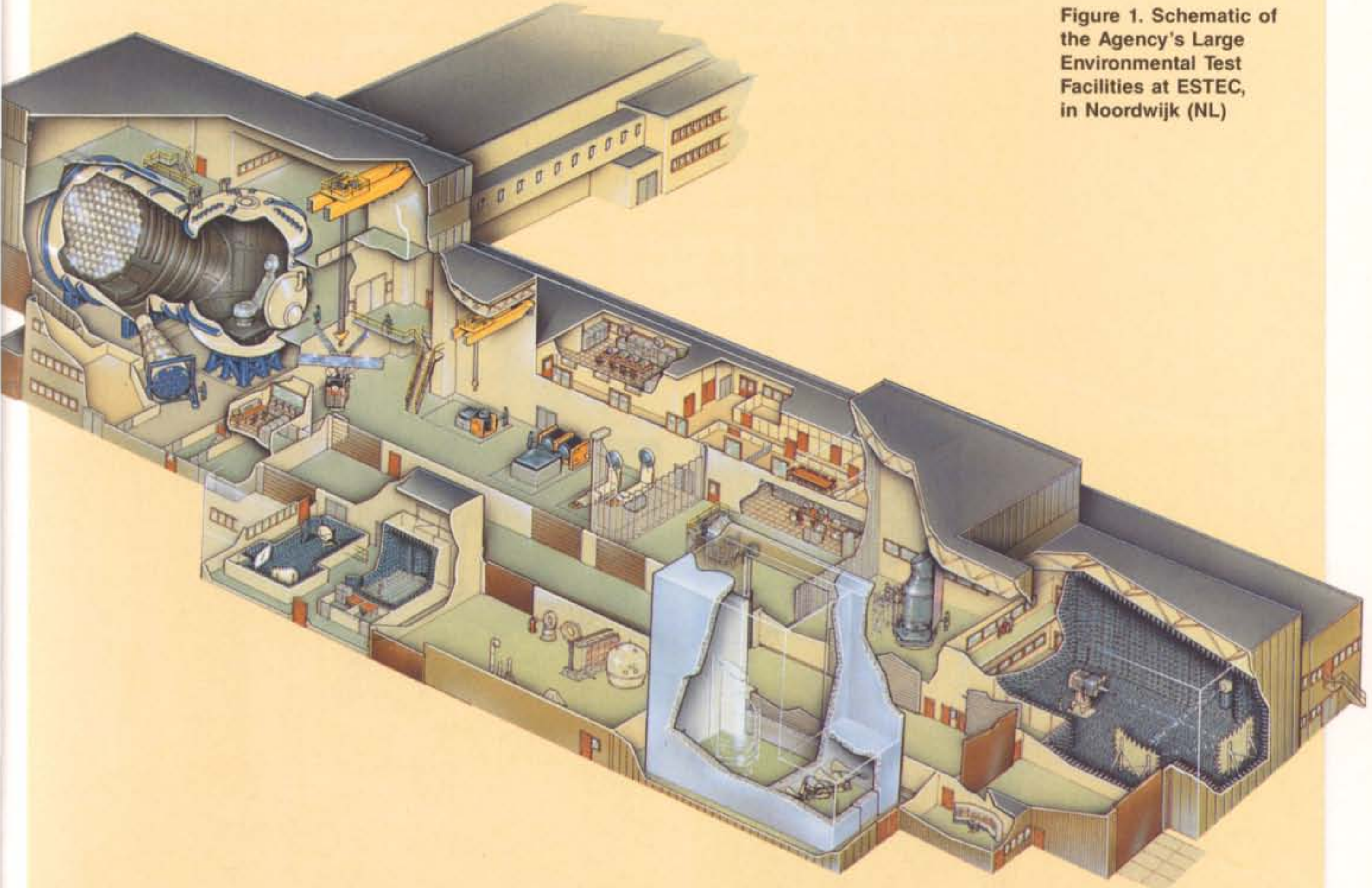


Figure 1. Schematic of the Agency's Large Environmental Test Facilities at ESTEC, in Noordwijk (NL)

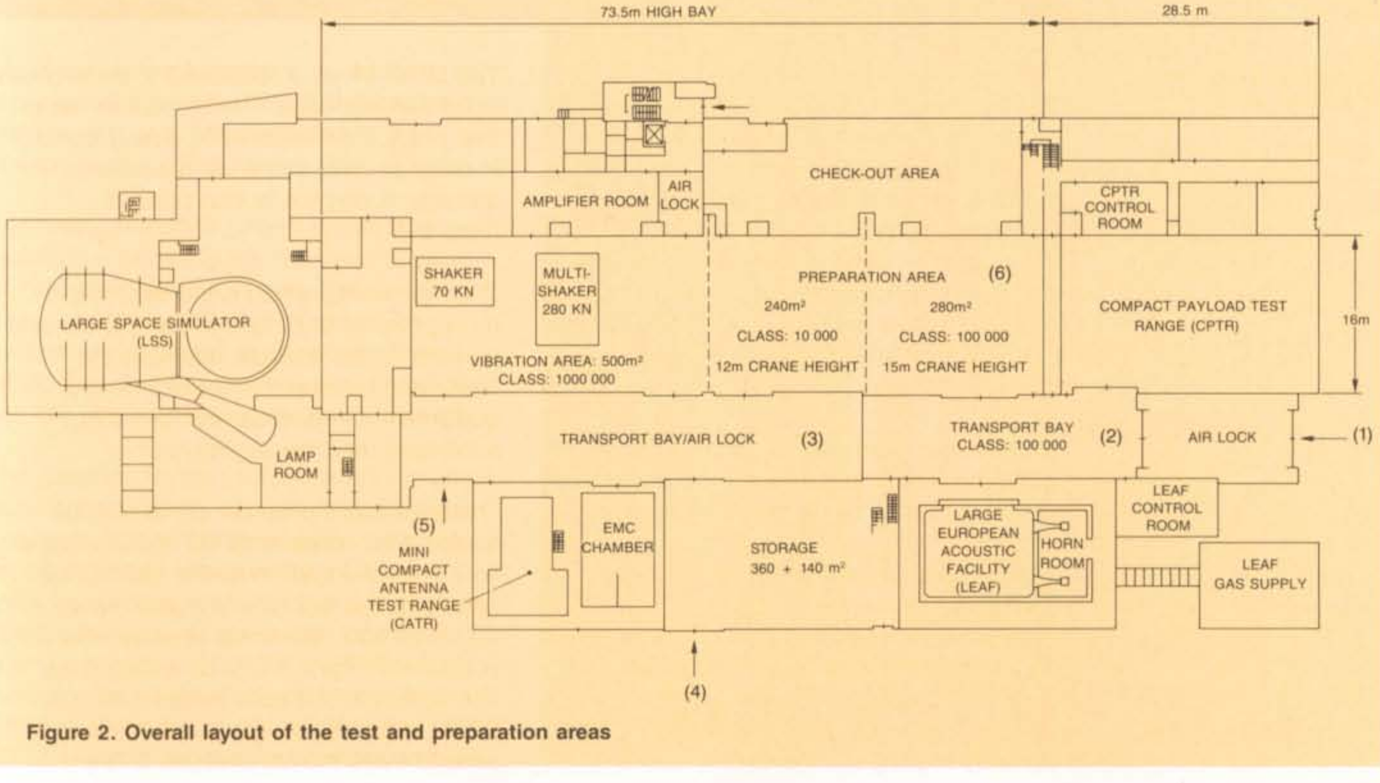


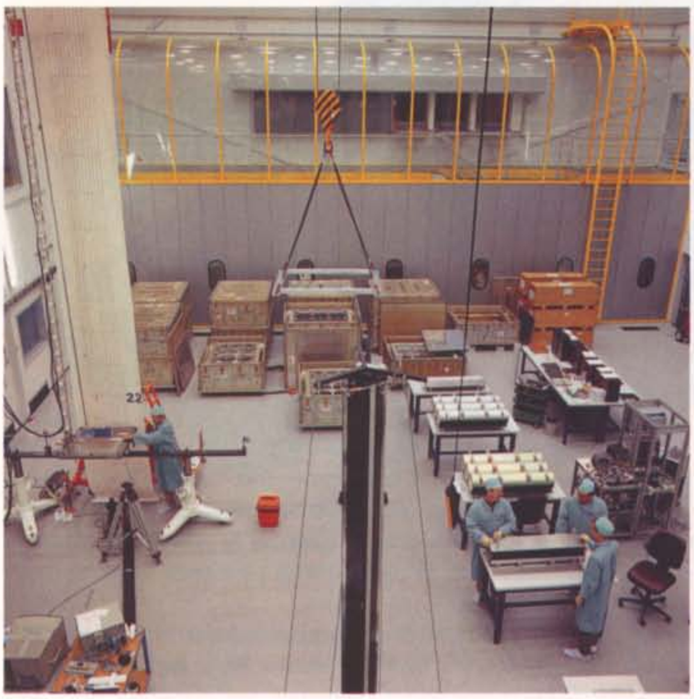
Figure 2. Overall layout of the test and preparation areas

Preparation Area, the Large European Acoustic Facility, or the Compact Payload Test Range. It can also be transferred to the existing transport bay (3), and thence to any of the existing facilities such as the shakers, LSS, etc.

The Test Preparation Area
This new area (6) is a Class-100 000 clean room, with a floor area of 280 m^2 and a 160 kN bridge crane with a hook height of 15 m. Items for test enter the transport bay through a large door, 7 m wide and 15 m high.

Figure 4 gives an impression of the spaciousness of the 'high-bay' clean room, which is about 74 m long when the folding doors are open.

The Large European Acoustic Facility (LEAF)
As implied above, the LEAF, which has been operational since June 1990, complements other large environmental test facilities at ESTEC like the LSS and the MSS. Its addition will allow large spacecraft to be tested completely in terms of vibration, acoustic and solar simulation.



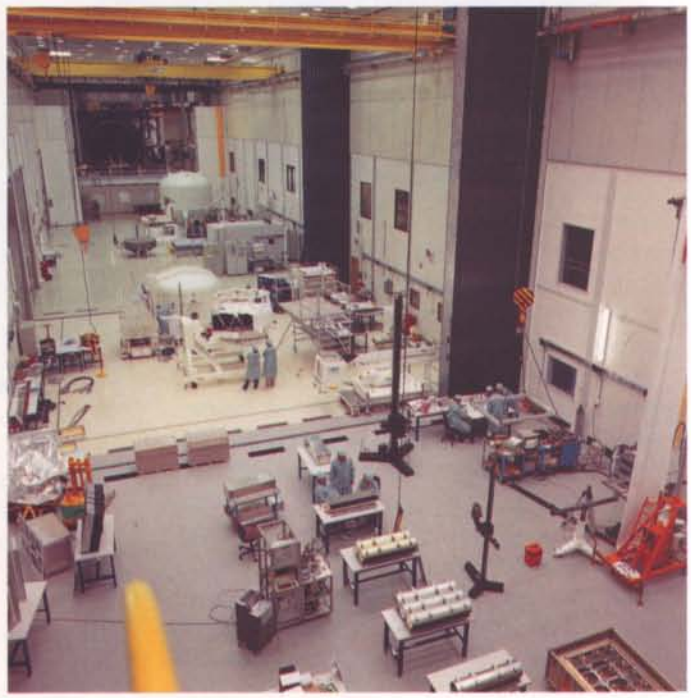


Figure 3. The new Test Preparation Area

Figure 4. The High-Bay Clean Room

The new area is separated from the existing one by a large folding door (dotted lines) which can be opened to combine the two rooms. This folding door makes it possible to move test hardware by crane to those test facilities (vibrators, LSS, etc.) located in the adjacent clean-room areas. As the roof of the 'old' building is lower than that of the new one, provisions have been made for an overlapping crane zone to facilitate easy hardware transfer.

A dedicated room next to the clean room allows check-out equipment to be connected to the spacecraft being prepared for a test.

The new Test Preparation Area has already been used for the dismantling of a Long-Duration Exposure Facility (LDEF) experiment after its return from a stay of more than five years in orbit (Fig. 3). A special test on a Hubble Space Telescope solar-array boom is currently in progress there.

The LEAF allows a spacecraft to be exposed to an acoustic noise environment similar to that which it will experience during launch, in order to verify that it will not suffer any damage during the launch process (Figs. 5 & 6).

The new facility, which is the largest and most powerful of its kind in Europe, consists primarily of the acoustic chamber, the horn-room housing the noise-generation equipment, the gaseous-nitrogen (GN_2) subsystem, and the control room.

The reverberant chamber (1), which has reinforced-concrete walls 0.5 m thick, has a floor area of 9 mx11 m and is 16.4 m high. Access to this facility, which also meets Class-100 000 cleanliness requirements, is via a full-height, 7 m-wide sliding door. The complete chamber, weighing about 2000 t, is seismically mounted on rubber pads to avoid the transmission of any

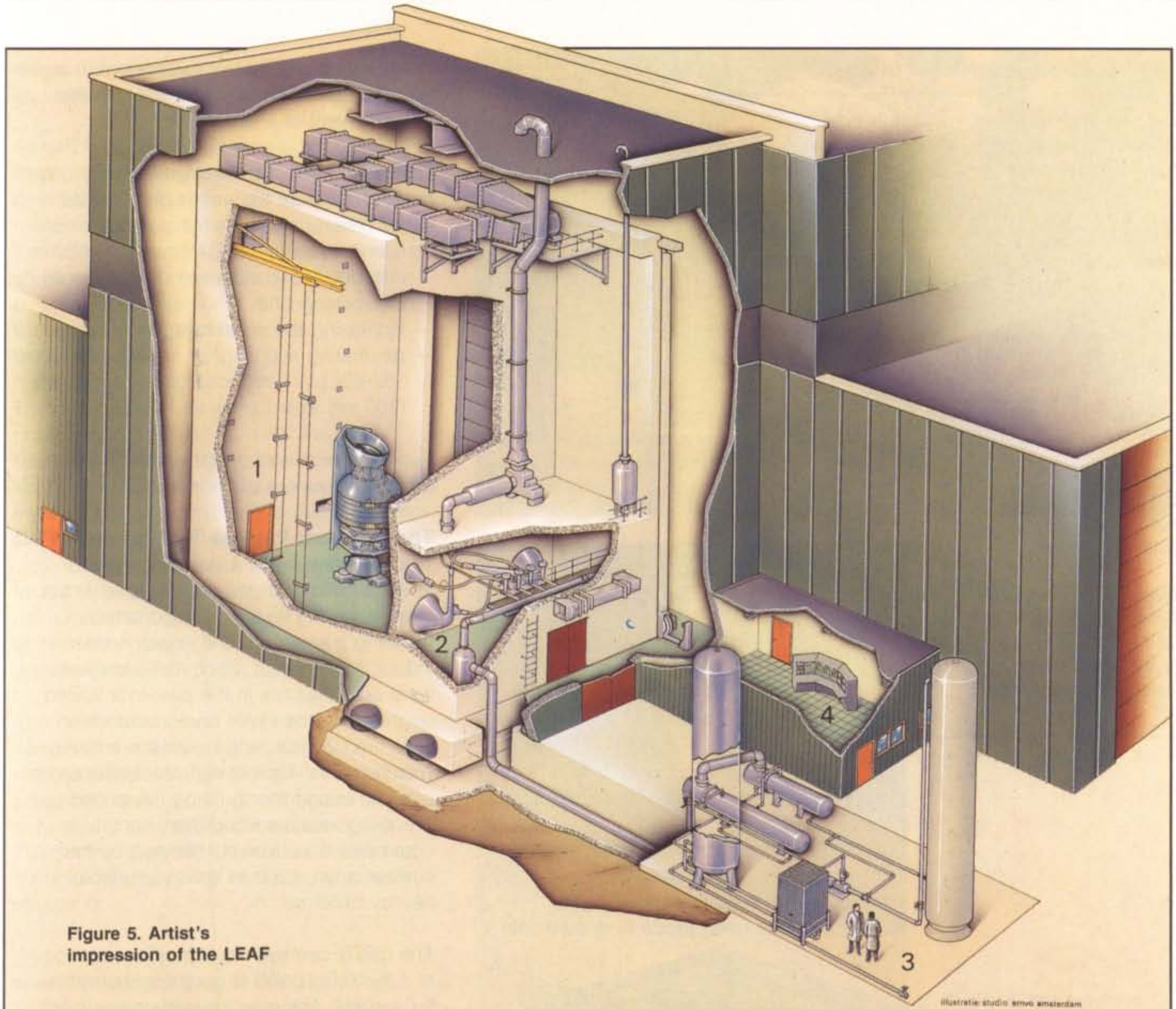
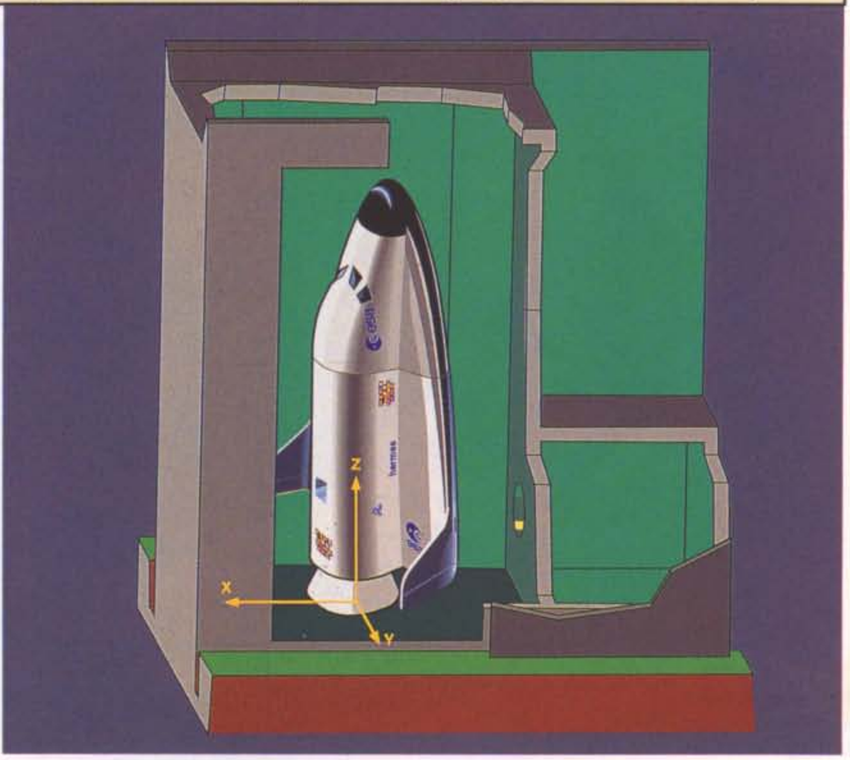


Figure 5. Artist's impression of the LEAF

Figure 6. Schematic of Europe's Hermes spaceplane in the LEAF facility



vibrations via the foundation. In addition, it is surrounded by a building with absorbing walls to attenuate noise radiated to the outside to acceptable levels.

The noise-generation system in the 'horn-room' (2) adjacent to the chamber consists of four noise generators and associated horns interfacing with the chamber. The generators are driven by gaseous nitrogen which – unlike compressed air – precludes any risk of contaminating the item under test.

The gaseous-nitrogen subsystem (3), located outside the building, can generate different pressures, temperatures and flow rates by vaporising liquid nitrogen (LN_2) using hot water as an energy source. It is designed to operate for up to 45 min at the maximum sound pressure level of 154.5 dBL before having to be replenished with hot water and nitrogen. Considering that a typical test lasts about 1–2 min, the system provides ample

Table 1. Main characteristics of the LEAF

Chamber Volume	: 1624 m^3
Chamber Dimensions	: 9 m × 11 m × 16.4 m (width × length × height)
Main Door Access	: 7 m × 16.4 m (width × height)
Suspension Points	: 9 points of 80 kN load capacity 35 points of 15 kN load capacity
Max. Crane Load	: 160 kN
Cleanliness	: Class 100 000
Temperature Range	: 20° ±2°C (during test)

Centre Frequency (Hz)	Sound Pressure Level (dBL)	
31.5	136.5	specified octave band pressure levels in empty chamber at 154.5 dBL
63	141.5	
125	147.5	
250	150.5	
500	147.5	
1000	144.5	
2000	137.5	
4000	131.5	
8000	125.5	

Overall Sound Pressure Level Range	: 125 dBL – 154.5 dBL
Field Homogeneity in Test Volume	: ±2 dBL
Control Tolerance of Sound Field	: ±1.5 dBL overall
Noise Measurement	: 16 microphones
Data Acquisition	: 250 accelerometers, and 50 strain gauges

capacity for conducting pre-tests and test campaigns without interruption.

The control room (4) ensures proper operation of the facility according to the applicable test specifications. Special provisions have been made to ensure safe operation and to protect the specimen under test against excessive noise levels in the unlikely event of a system malfunction.

The LEAF's structural design includes growth potential to meet the needs of future still larger programmes, via the possibilities of:
- lateral extension of the chamber volume
- installing a second large door opposite the existing one
- increasing the noise level to 158.5 dBL
- generating even higher noise levels (up to 162 dBL) in a reduced chamber volume (200 m^3).

Further design and performance characteristics are provided in Table 1.

The Compact Payload Test Range (CPTR)

The CPTR will allow a new test method to be applied that permits end-to-end radio-frequency (RF) testing of large complex radiating payloads of the Ariane-4 class in an indoor environment. Such measurements were only possible in the past to a limited degree, and then only on an outdoor or semi-outdoor test range, with the emitting station several kilometres from the receiving satellite. In addition to being influenced by prevailing weather conditions, such tests could also be adversely affected by the surroundings, such as ground surface, nearby buildings, etc.

The CPTR can work in a frequency range of 1.5–40 GHz and is particularly suitable for verifying link margins, self-compatibility, radiative patterns, ground coverage, and overall payload RF performance. It can also be used to carry out a range of electro-

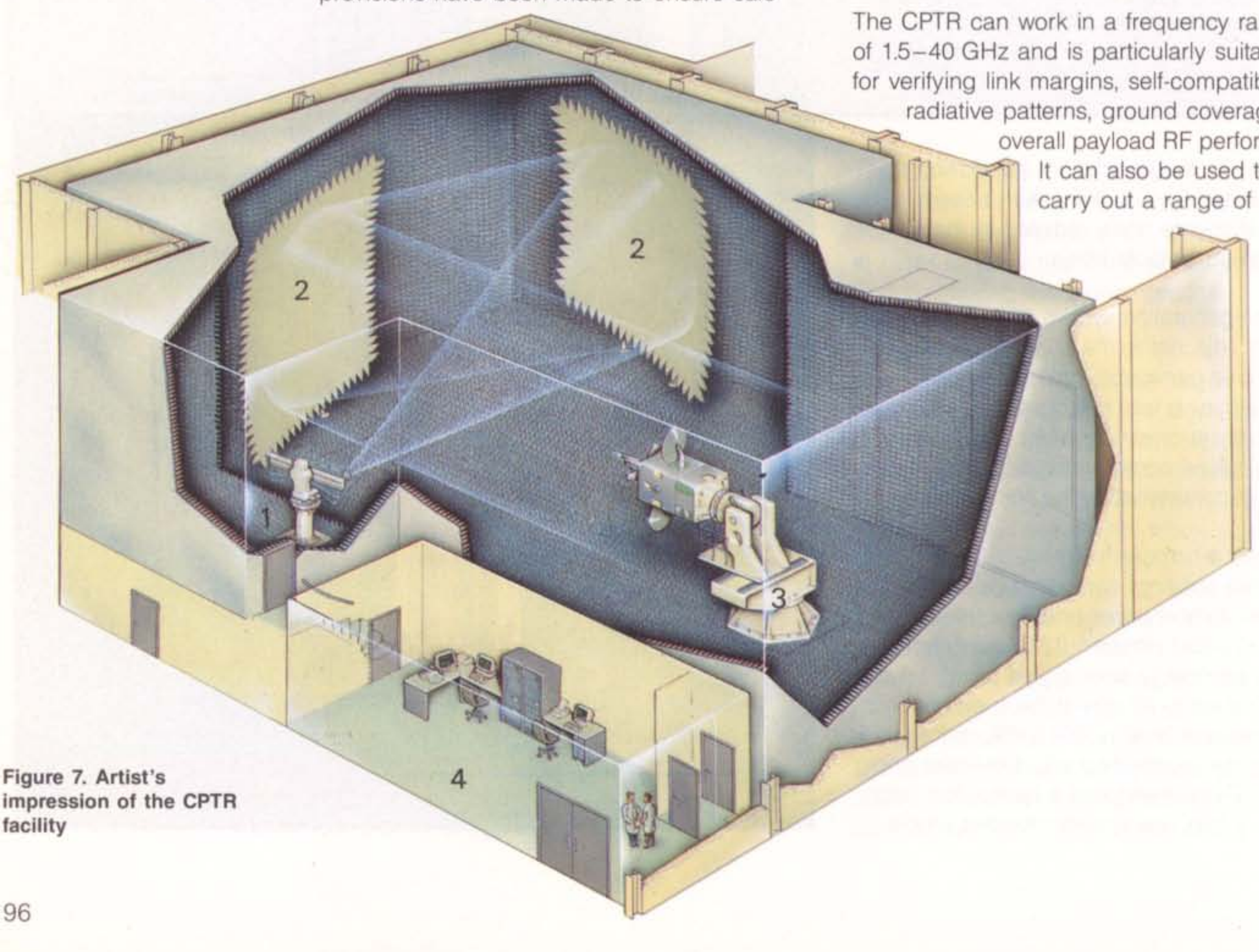


Figure 7. Artist's impression of the CPTR facility

magnetic compatibility (EMC) measurements on large test items.

All CPTR equipment is installed in a large, shielded, anechoic chamber (Fig. 7). Its walls are lined with absorber cones to reduce reflections to the desired level. The 10.9 mx9.6 mx24.5 m interior is air-conditioned and meets Class-100 000 cleanliness requirements. A large 6 m wide, 6.5 m high door provides access from the transport bay.

The main equipment items inside the chamber are the feedhorn (1), two large reflectors (2), and a turntable (3), which supports the specimen to be tested. Facility controls and data-acquisition systems are located in the adjacent control room (4). The RF beam emitted by the feedhorn is folded twice by the reflectors to produce a plane-wavefront zone, simulating that at the geostationary orbit, in a volume of approximately 7x5x5 m^3.

The most delicate and sophisticated hardware elements are the two dual curved reflectors, the machining of which called for advanced manufacturing techniques to achieve the requisite surface accuracy of 70 microns. Geometrical stability is ensured by employing very stiff and precise support structures.

The turntable (Fig. 8) can position a test specimen weighing up to 6000 kg about all three axes with high accuracy. The feedhorn(s) are also mounted on a scanning mechanism (Fig. 9), which can position them in different locations in the focal plane, allowing the performance of an earth station transmitting via the satellite to another station to be verified.

Table 2. Main parameters of the CPTR

Electrical characteristics	
Plane Wave Zone	7×5×5 m
Frequency Range	1.5 to 40 GHz
Amplitude Ripple	±0.2 dB
Phase Ripple	±4°
Taper	0.4 dB
Environmental characteristics	
Cleanliness Class	100.000
Temperature	20°C ±2°
Humidity	50% ±10%
Positioners	
Test Positioner	
Load Capacity	6000 kg
Reflectors	
Subreflector Dimensions	9.2×8.0 m
Reflector Dimensions	10.5×7.5 m
Surface Accuracy	70 microns (peak to peak)

Figure 8. The CPTR turntable

Figure 9. The feedhorn support in the CPTR

The design and performance characteristics of the CPTR are summarised in Table 2.

The availability of the CPTR as part of the ESTEC Integrated Test Centre offers the ideal possibility of being able to evaluate the performance of a payload both before and after any critical environmental testing (vibration, acoustic, solar simulation, etc.), in order to verify that its electrical performance has not been degraded as a result of the test.

At present, the CPTR is in its final assembly phase, with almost all hardware installed and acceptance-tested. The facility will be fully operational by the end of the year.

Computer Networking via High-Speed Satellite Links

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A computer-networking demonstration was begun at ESTEC in April 1990 using the 20/30 GHz payload of the Agency's Olympus communications satellite. In setting up this experiment, special attention was paid to minimising the need for specialised hardware or software development by employing off-the-shelf hardware, software, and communications protocols wherever possible. The Olympus satellite channel was treated as a straightforward point-to-point link.

Two immediate conclusions drawn from the experiment were that:
- **by carefully selecting the computer operating systems and communications protocols at the outset, the interconnection of two Local-Area Networks (LANs) requires no special developments on the computer side**
- **a large family of software applications can be installed and used with practically no modification.**

Introduction

Computer networking has been a major activity in the computing field for the last two decades, and several such networks are currently spreading worldwide, using a mixture of terrestrial and satellite links. The Space Astrophysics Network (SPAN), Bitnet and EARN are typical examples.

As yet, however, there is little experience available concerning the interconnection of Local-Area Networks (LAN) using high-speed links to and from satellites, and in particular in coping efficiently with both the high transmission rates (megabits per second) and the substantial round-trip signal delays (of the order of 0.5 s).

The purpose of the experiment at ESTEC was to show that, given that there is a point-to-point satellite link available, it is possible to interconnect two LANs efficiently using exclusively off-the-shelf hardware, software and communications protocols. So far, only point-to-point communication has been tested, but it is intended to demonstrate more complex configurations during subsequent phases of the programme.

Hardware configuration

The experiment was conducted using two physically separate networks, called the 'local' and the 'remote' network, in use in the ESTEC Mathematics and Software Division (Fig. 1).

The remote network includes a work station (Sun Sparc 1) with a local hard disk and a laser printer, operating under Unix, a portable personal computer (Toshiba 5100 PC) with an MS-DOS operating system, and a terminal (NCD-16, X-11 environment) running as a network server for graphics applications.

Together with other equipment, the local network includes a dedicated work station (Sun 3/260) with hard disk, running under Unix. This network is connected to the Division's own local area network and the ESTEC LAN, giving access to the IBM mainframe, SPAN, EARN, Internet, etc.

The remote and local networks are both based on Ethernet, using the Unix TCP/IP protocol suite. Digital VAX VMS computers are accessible on the network using Digital's TCP/IP software (VMS/Ultrix Connection). The two networks are connected to the satellite modem via a network 'router', providing a hardware interface between the Ethernet network and the V11 modem.

The two modems, operating from 32 kbit/s to 4 Mbit/s, are each connected to one transmit and receive chain of one TDS-6 transportable Earth station available at ESTEC, transmitting and receiving at two different frequencies via the 20/30 GHz Olympus payload.

Operating system and protocols

To minimise development time, no special hardware or software has been commissioned. The Unix TCP/IP suite of protocols was selected from the outset because it is

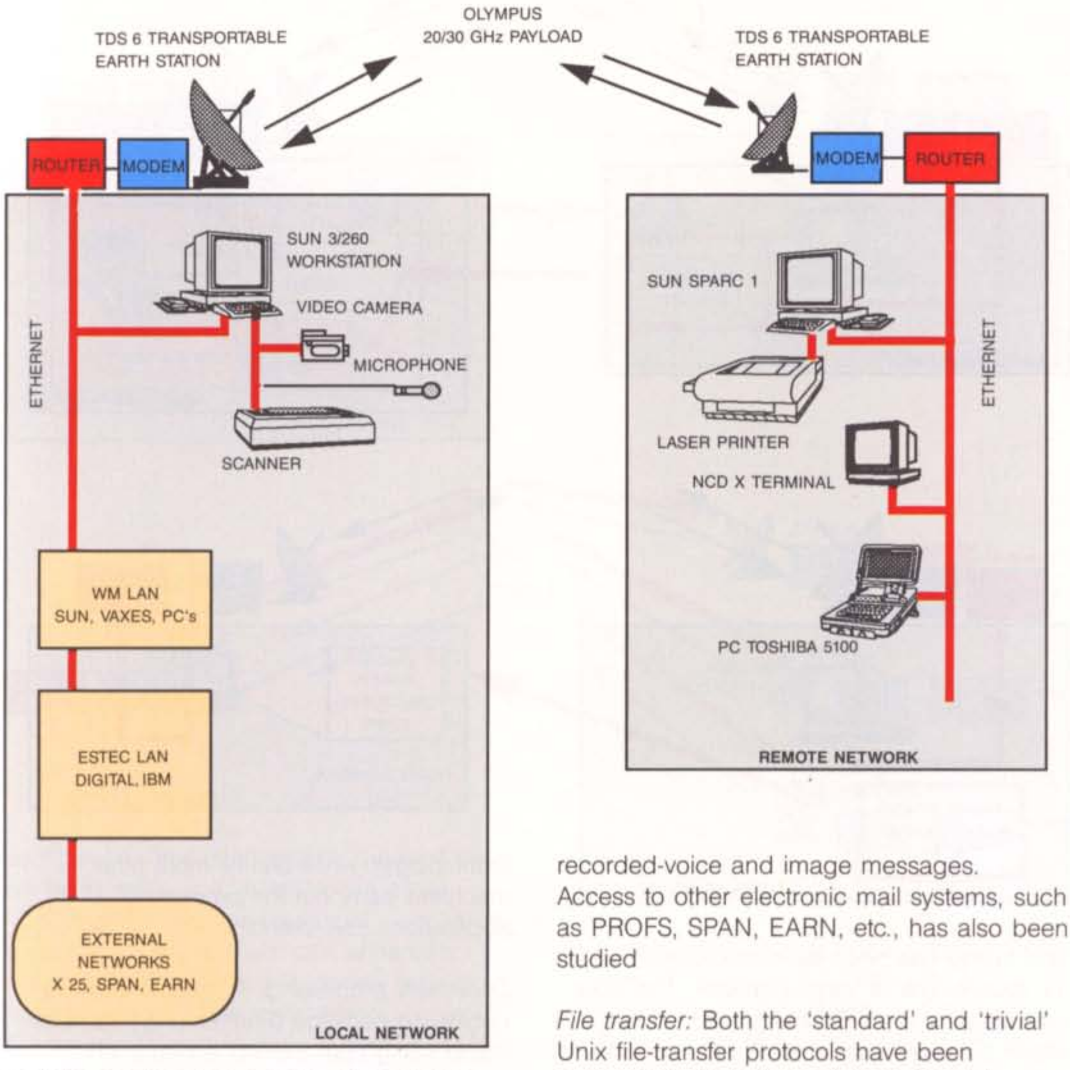


Figure 1. Hardware configuration for the computer-networking experiment

available on the vast majority of computer platforms accessible via the ESTEC network. It has also been well tested, maintained and integrated into the Unix operating system, providing immediate access to a wide variety of software applications such as file transfer, electronic mail, remote log-in with terminal emulation, etc.

Currently, only Unix computers (Sun) and PCs (using Sun PC-NFS software) have been integrated into the network under test. The inclusion of Digital VAX VMS work stations and computers is planned, however, in order to study the behaviour of other protocols such as Decnet over the satellite link.

Software applications
A variety of standard applications, mostly Unix-based, have already been tested over the satellite link:

Electronic mail: The Unix simplified mail-transfer protocol has been successfully tested over the satellite link. A generalised Unix mail multi-media tool (prototype, under Unix Sun-view) has also been successfully tested, allowing the transmission/reception of text, recorded-voice and image messages. Access to other electronic mail systems, such as PROFS, SPAN, EARN, etc., has also been studied

File transfer: Both the 'standard' and 'trivial' Unix file-transfer protocols have been successfully tested over the satellite link at various speeds. The transferred files contained all types of data, ASCII and binary image files, and ranged from a few bytes to several megabytes in size.

Remote log-in: The standard Unix remote log-in (Telnet) facility has been used to access computers on the local network from the remote network. It has been shown to be possible, for example, to access the ESTEC IBM mainframe from a portable PC, using IBM 3270 software emulation (public-domain software), via the satellite link. Several other remote log-ins have been tested both with computers on the LANs at ESTEC, and external networks such as EARN, X25 and SPAN.

Network File System (NFS): The NFS software (available on Sun and Digital work stations and on PCs) allows the sharing of disk space transparently between several computers with different operating systems. It is possible, for instance, for a PC user on the remote network to access files on a Sun or Digital disk on the local network as if they were on his own disk.

Figure 2. The Network File System (NFS)

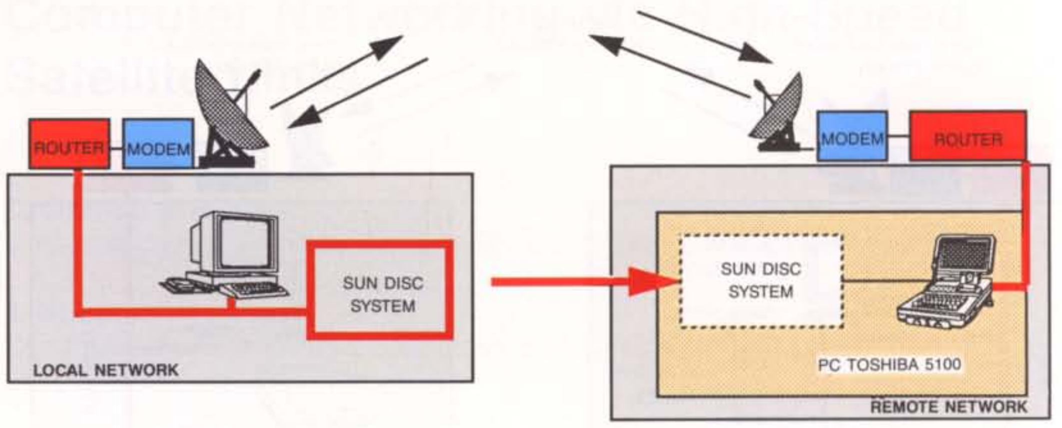
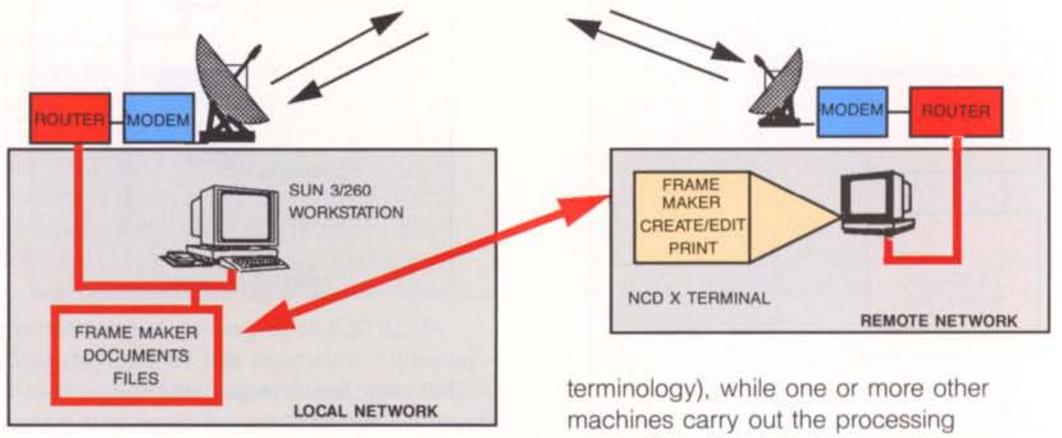


Figure 3. The setup for the publishing-package transmission test



This facility has been successfully tested over the satellite link at various speeds. The main advantage of an NFS configuration is that it allows a remote user to work on a file without first having to transfer that file to their own system.

Remote database access: Two database management systems, Oracle and Sybase, have been tested over the satellite link. The first was accessed by logging-in remotely using the Telnet facility described above (VT100 terminal emulation), making it possible to access, retrieve and update data on the central database via the satellite link.

The Sybase system is more elaborate in that it uses stored procedures to minimise the volume of transfer over the satellite link. The test database used in this case was a prototype developed for the Agency's CODE* project, containing information on satellite earth-station equipment and its characteristics.

X11 environment: This network windowing system (MIT Release 4, public-domain software) proved to give reasonable performance when used via the satellite link. It allows a computer terminal or work station with graphics capabilities to control the display software only (the 'server' in X11 terminology), while one or more other machines carry out the processing applications (the 'clients').

Document processing: A popular desktop publishing package (Framemaker) has been tested using both the X11 environment (with an NCD-16 terminal) and Sun's proprietary windowing system (Sunview) over the satellite link, without any particular difficulty. Documents can thus be created, edited, printed and distributed from a remote terminal.

Graphics/images: A graphics data-analysis software package (PV-Wave) has been used successfully to display pixel images, scanned images, ERS-1 Synthetic Aperture Radar images, etc., contained in files on the local side on the remote network. The image size was typically 1024 by 1024 pixels, with 8 bits per pixel.

Video-frame transmission: The goal here is to extract video frames from a camera in the local network, transmit the video buffer to the remote network, and display the video picture on the remote work-station's screen. Once a technical video-board hardware problem has been solved, it is expected to be able transmit 5 to 10 frames per second without compression.

Future plans

So far only the point-to-point (LAN-to-LAN)

* CODE is an interactive data network used for information dissemination and exchange, which is operating as part of the Olympus Utilisation Programme

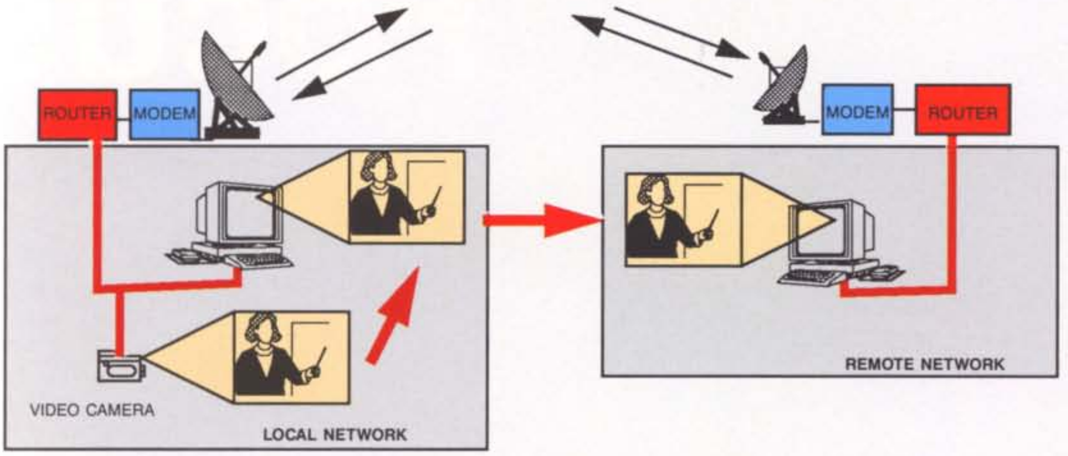


Figure 4. The setup for the video-frame transmission test

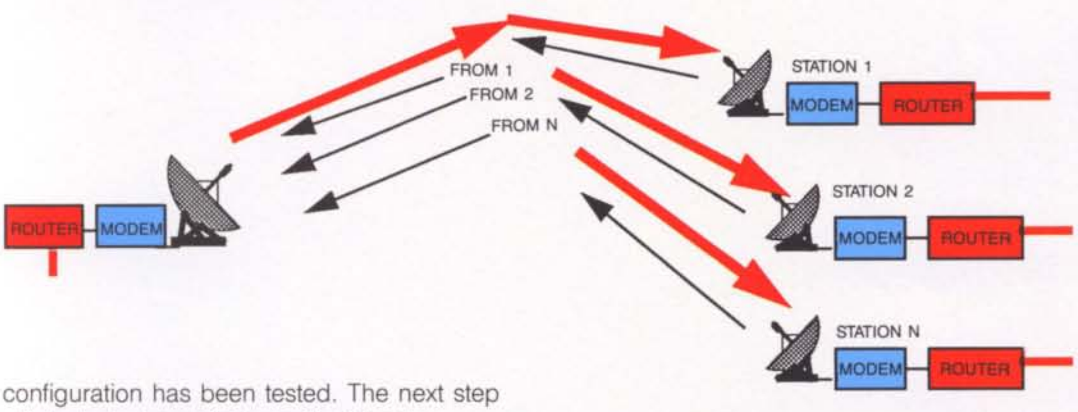


Figure 5. Point-to-multipoint networking philosophy

configuration has been tested. The next step will be to test a point-to-multipoint setup – a so-called 'star configuration' – in which a central station, or 'hub', can undertake simultaneous transfers with several remote stations using a static, pre-defined, Frequency-Division Multiple Access (FDMA) scheme to communicate with the satellite. The third step will be to test a point-to-multipoint configuration, but using a dynamic scheme for FDMA such as that designed for the Agency's CODE experiment.

A final step could be to test a more symmetrical system in which every station could address any other on the network using a static or dynamic FDMA mechanism.

Conclusion

The work conducted to date has shown that:

- It is possible to interconnect two LANs quickly and easily via satellite, provided a point-to-point satellite channel is available and the correct combination of computer hardware, software and communications protocols is selected.

- A wide variety of software applications can be installed and used with practically no modification via such a network.

- Once implemented and properly tuned, the presence of a satellite link in the network is almost invisible from the user and application points of view.

- A throughput of about half a megabit per second has been achieved with crude tuning, on a single end-to-end circuit. Several such circuits can be operated simultaneously via the satellite in a manner transparent to the user in order to use the channel's bandwidth efficiently.

Acknowledgment

The success of the work that has been described, which required the assembly of a considerable amount of equipment, computers, modems, and earth stations, as well as arranging satellite access, was due in large part to the dedication and enthusiasm of the people involved, on both the telecommunications and the computer sides.

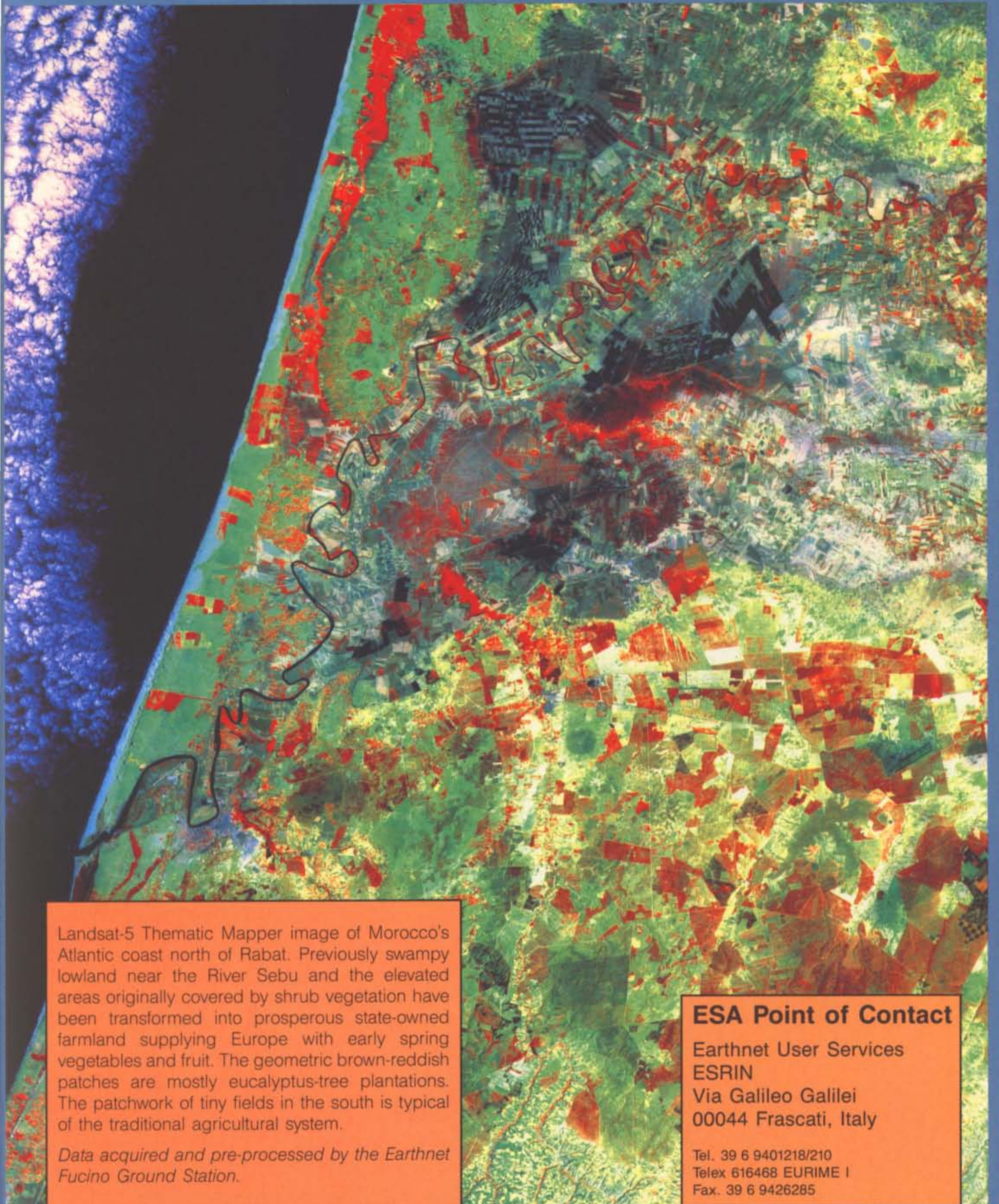
The contributions of Sun Microsystems (NL), who loaned computer hardware, and BIM (B), who provided the communications equipment and also gave system-software advice, are gratefully acknowledged.

Focus

Landsat-5 Thematic Mapper image of Southwest Sardinia, showing the Gulf of Cagliari (right). Cagliari and the surrounding area show clear signs of human activity, i.e. settlements, harbours, industrial installations and salt mining. The red colour in the mountainous areas indicates vegetation, interrupted by degraded and highly eroded land, apparent as brownish-yellow spots.

Data acquired and pre-processed by the Earthnet Fucino Ground Station.

Earth



Landsat-5 Thematic Mapper image of Morocco's Atlantic coast north of Rabat. Previously swampy lowland near the River Sebu and the elevated areas originally covered by shrub vegetation have been transformed into prosperous state-owned farmland supplying Europe with early spring vegetables and fruit. The geometric brown-reddish patches are mostly eucalyptus-tree plantations. The patchwork of tiny fields in the south is typical of the traditional agricultural system.

Data acquired and pre-processed by the Earthnet Fucino Ground Station.

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First Science Images from ESA's Faint Object Camera

In Brief

ESA's Faint Object Camera (FOC) on the NASA/ESA Hubble Space Telescope (HST) has been carrying out its first real scientific observations. These images have been obtained as part of a test programme designed to evaluate the scientific performance of both of the HST imaging cameras, given the optical problem with the Telescope's primary mirror.

The prime objective of the HST mission is to obtain images of astronomical objects in approximately ten times sharper detail than that obtainable by ground-based telescopes. The accompanying series of images taken with the Faint Object Camera clearly demonstrates that this objective can in many cases be fulfilled, notwithstanding the Telescope's optical problems.

The so-called 'spherical aberration' of HST's primary mirror does not result in blurring of the whole image. On the contrary the HST images have an extremely sharp central core, surrounded by a much larger, but fainter, diffuse 'halo'.

Figure 1 is a recent image obtained with the FOC. This exposure was taken in the f/96 camera in visible light, at a wavelength of 487 nm, and it shows

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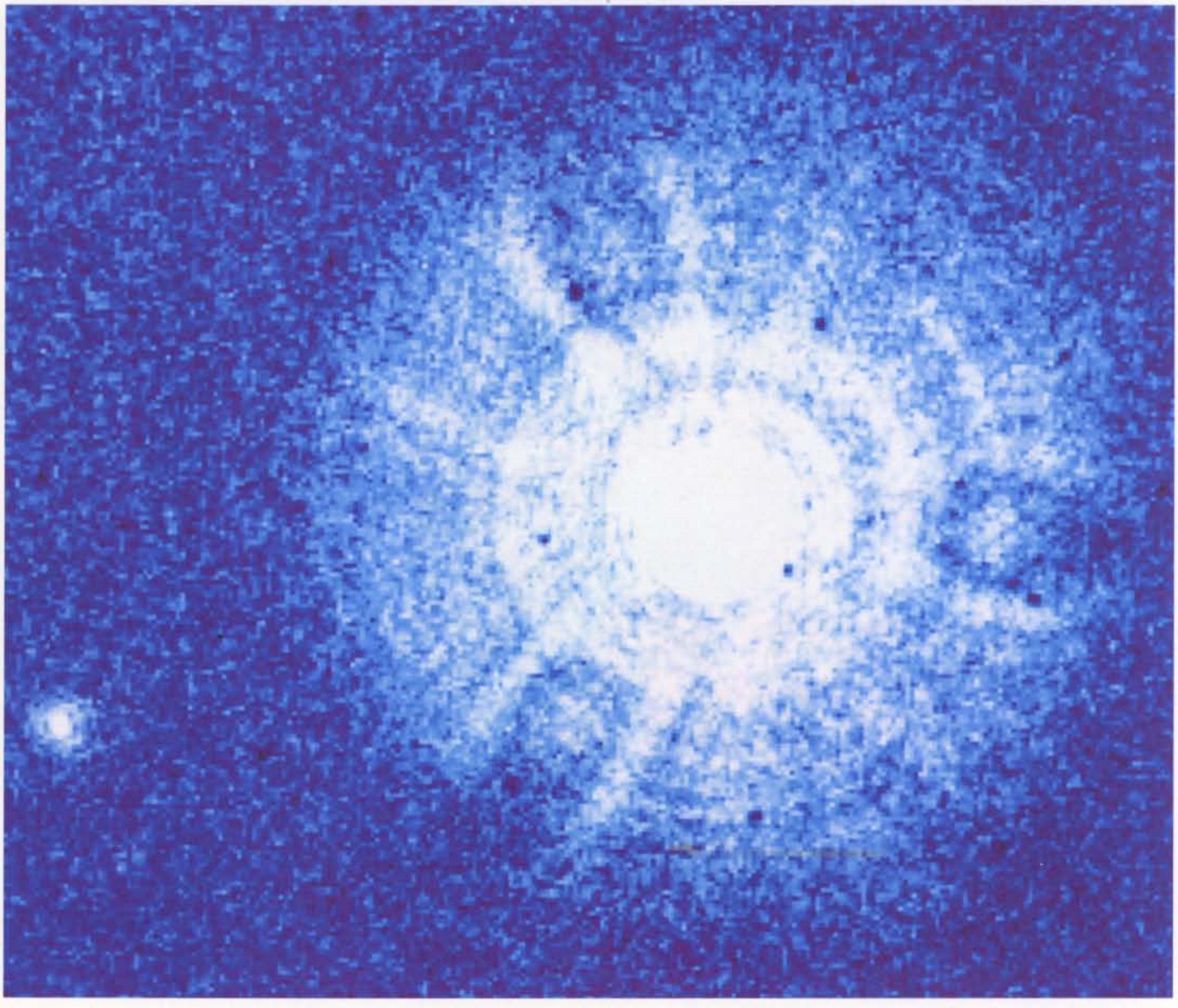


two stars, about 3.6 arcsec apart, whose brightness differs by a factor of about 100. The false colour brings out the details of the fainter outer parts of the image.

Although the light from the brighter star is spread over a huge circle corresponding to a diameter of just over 4 arsec, the central peak of the image is nonetheless extremely sharp. This sharp image core is most readily seen in the fainter star on the left; the central core has a diameter corresponding to an angular width of only 0.07 arcsec.

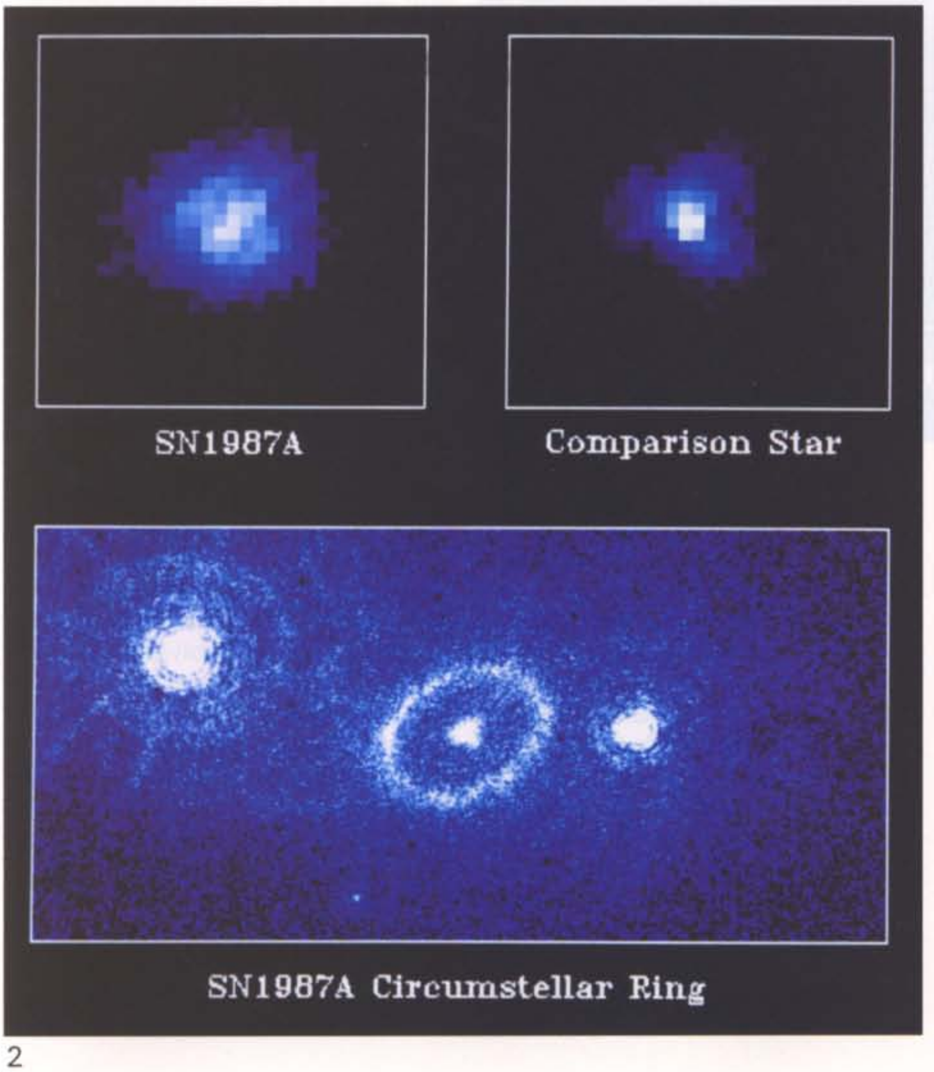
The scientific loss introduced by the spherical aberration is not one of image sharpness but rather a loss in sensitivity because the sharp central core – which carries all the useful information in the image – contains only about 17% of the total light, with the remainder contributing to the general haziness of the image.

Supernova 1987A
Ever since its initial explosion in February 1987, astronomers worldwide have been closely monitoring the evolution of SN1987A, using both ground-based and space instrumentation. During the 3½ years following its discovery, the supernova initially increased its brightness by a factor of 100 and has since dimmed one million times in brightness from its peak intensity. This dimming has enabled astronomers to take a closer look at the supernova proper and its surroundings.

Based on theoretical and spectroscopic evidence, SN1987A is known to be expanding rapidly, with the outer regions of the exploding star being ejected at speeds between 2000 and 30 000 km/s. The supernova should by now have reached a size of approximately one tenth of a light year in diameter, about 100 times larger than the Solar System. Since SN1987A is located 170 000 light years away, its current angular size as seen from Earth is expected to be about 0.1—0.2 arcsec in diameter. This angular extent is too small to resolve with ground-based telescopes.

Figure 2 (upper left frame) is one of the first images of SN1987A taken with the FOC. This image was taken in ultraviolet light at a wavelength of 275 nm. In comparison with the corresponding image of an unresolved comparison star from the same exposure shown in the upper right frame, it can be seen that the image of SN1987A is significantly broader and clearly extended in size. Although even the FOC's resolution is still too coarse to clearly reveal much detailed structure, this is the first time that the exploding outer envelope of SN1987A has been photographed directly, clearly demonstrating the power of the Telescope. The angular diameter of SN1987A measured from the images is about 0.15 arcsec – a value very close to expections and confirming the predictions of its current size.

A second, less magnified, FOC image of SN1987A and its surroundings is shown in the lower frame of Figure 2. The central object is SN1987A itself and the bright objects on each side are relatively bright companion stars. The faint 'halos' surrounding these brighter stars are not real, but are due to the spherical aberration. This image, taken in the light of twice-ionised oxygen at a wavelength of 501 nm, reveals a curious luminescent ring surrounding SN1987A.



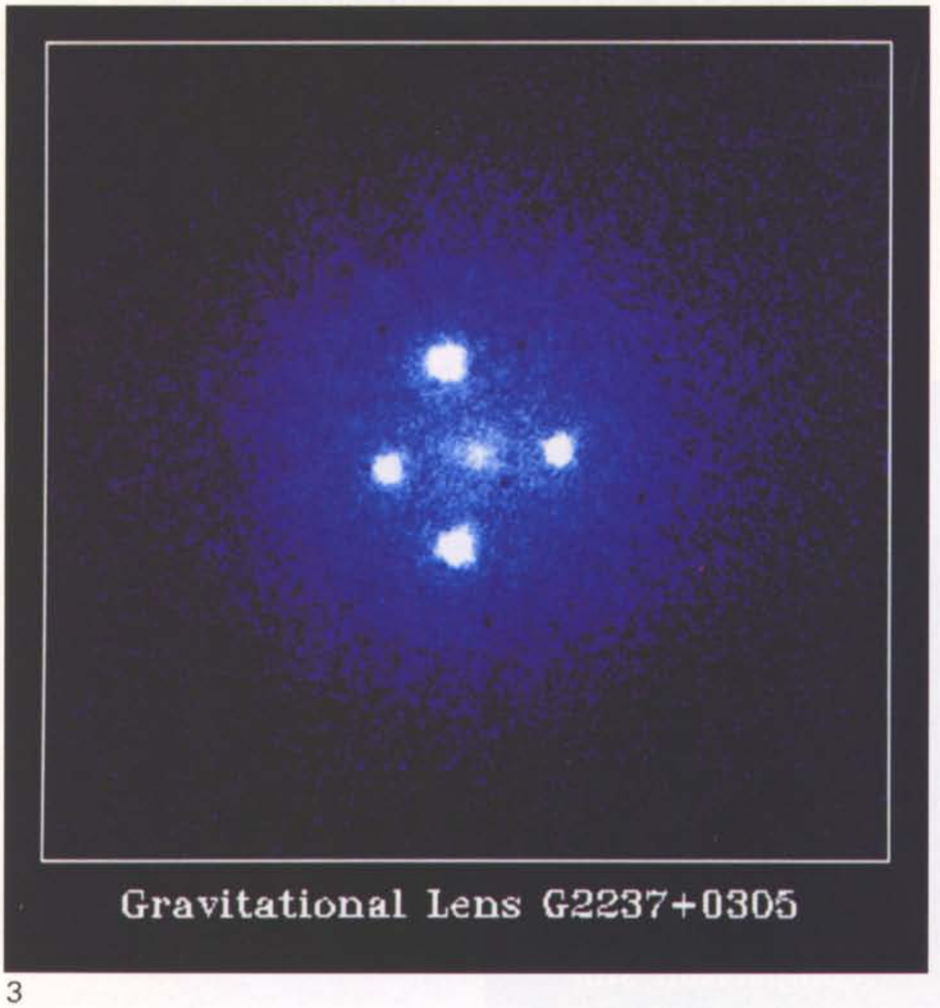
The existence of this ring had already been gleaned from both ground-based and ultraviolet space observations, but the FOC images have provided a far clearer view of its structure. The angular separation between the ring and SN1987A averages about 0.8 arcsec. At the distance of the Large Magellanic Cloud, this corresponds to 0.75 light years. Since this distance is too large for the ring to comprise material ejected by the supernova explosion, astronomers speculate that the ring must have existed prior to the explosion, in the form of a gas ring ejected and shaped by the 'stellar winds' from the progenitor supergiant star in the course of some 10 000 years prior to the supernova explosion. The ring material was then ionised and heated by the intense flash of radiation emanating from the supernova. This radiation reached the ring within the first year of the explosion and it is still glowing today.

The presence of this ring provides astronomers with an important clue in determining the nature and history of the progenitor star that exploded as SN1987A.

2

The gravitational lens G2237+0305

The FOC has provided the most detailed image ever taken of the gravitational lens G2237+0305, sometimes referred to as the 'Cloverleaf' or the 'Einstein Cross'. Figure 3 shows four images of a very distant quasar which has been multiply-imaged by a relatively nearby galaxy acting as a gravitational lens. The angular separation between the upper and lower images is 1.6 arcsec.



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The quasar is at a distance of approximately 8 billion light years, whereas the galaxy, at a distance of 400 million light years, is twenty times closer. The light from the quasar is bent by the gravitational field of the galaxy, producing the four bright outer images seen in the photograph. The diffuse central object is the bright central region of the galaxy.

Gravitational lensing occurs when the light from a distant source passes through or close to a massive foreground object. Depending on the alignment of the foreground and background objects with the line-of-sight to Earth, several images of the background object may be seen. In fact, astronomers expect that a faint fifth image of the quasar should be present near the centre of the galaxy in G2237+0305. Careful image processing will be needed to determine if the fifth image is actually seen in this FOC exposure.

Gravitational lenses, such as G2237+0305, are useful probes of many types of phenomena that occur in the Cosmos. For example, it is possible to 'weigh' the foreground galaxy by measuring the relative positions and the brightnesses of the different images of the quasar. With the high resolution of the FOC images, it should be possible to do this more accurately. Gravitational lenses also offer the possibility of determining the elusive Hubble Constant – a fundamental measure of the size and age of the Universe – by measuring the time delays in changes in brightness of the lensed images.

Detailed analysis of this fascinating image and others to be observed later with the Hubble Space Telescope will provide a wealth of information on lensing galaxies and the process of gravitational lensing itself.

R Aquarii, the nearest exploding star

One of the closest stars known to undergo violent eruptions that spew out huge quantities of processed nuclear material into the surrounding space, R Aquarii was studied intensively by HST's namesake, Edwin Hubble, in the 1930s and 40s, in an effort to understand the mechanism that powers the cataclysm. The instrumentation then available allowed him and his colleagues to observe only the outer rapidly expanding fringes of the fireball and to surmise that R Aquarii had exploded some 600 years ago. It has become clear since then that R Aquarii has actually undergone a series of violent eruptions, the latest probably occurring in the late 1970s.

R Aquarii is an example of a class of double stars called symbiotic novae. In these objects, it is speculated that the outburst occurs near or on the surface of a hot, compact, probably very old star that has already shed its outer layers to become a white dwarf. This star is violently reactivated by large quantities of fresh material falling onto it from a very nearby stellar companion. Fortified with fresh fuel, the white dwarf experiences an extremely rapid burst of nuclear burning akin to a hydrogen bomb. The energy released powers the ejection of a a good part of the outer layers of the star at speeds of up to several hundred thousand kilometers per hour.

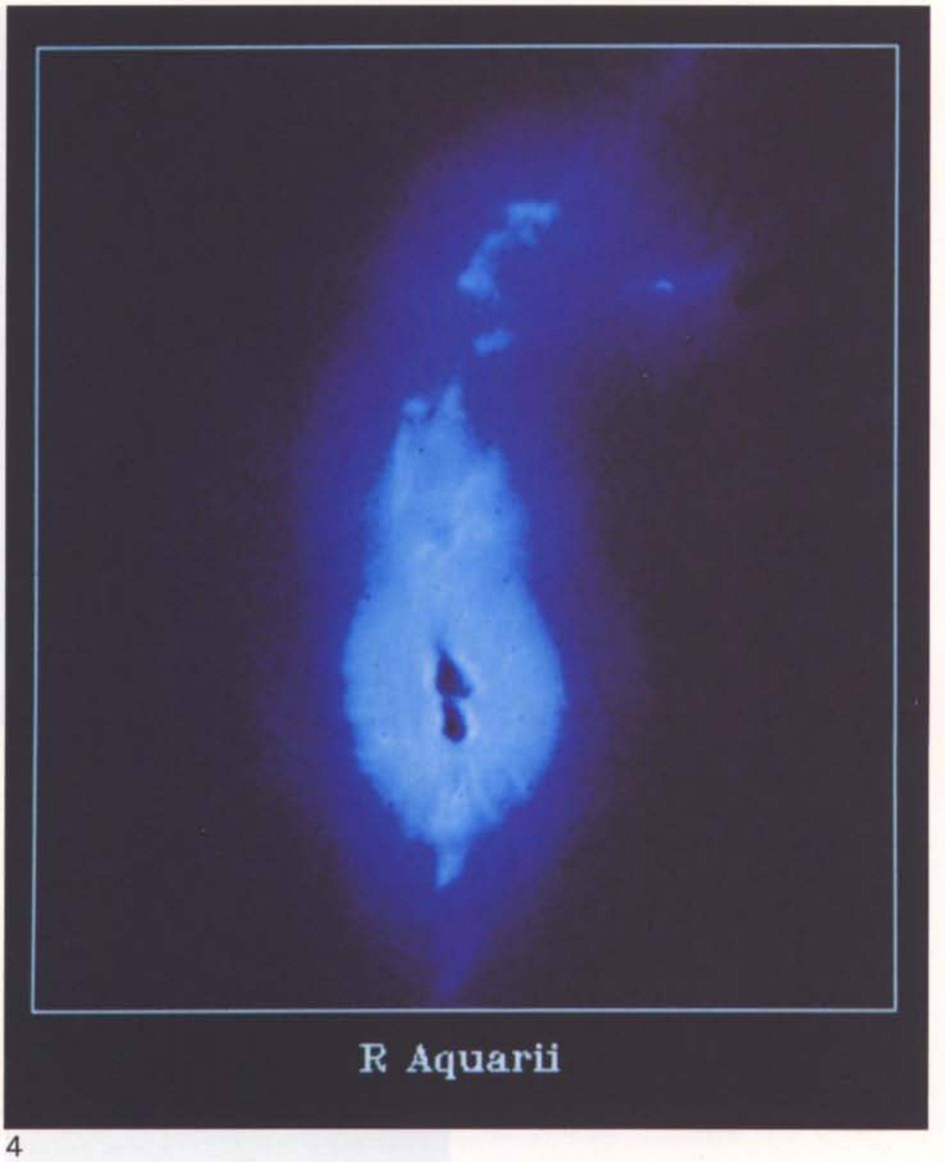
These events have more than just a passing interest to astronomers and laymen alike in that this is one known way — besides the enormous but extremely rare supernova events — to release the chemical elements heavier than hydrogen and helium into the Interstellar Medium. Heavier elements like carbon, nitrogen, and oxygen are critical building blocks of planets like the Earth and life forms such as our own. These elements are formed in the deep interiors of stars where the temperature is high enough to fuse hydrogen and helium and where they remain unless released by a cataclysmic event.

At a distance of only 700 light years from Earth, R Aquarii is close enough to permit a detailed investigation into the cause and the circumstances of this facinating phenomenon. The unprecedented resolving power of the FOC has recently been trained on R Aquarii in order to witness at first hand the detailed development of the explosion.

Figure 4 is the first picture taken by the Hubble Space Telescope of a recent nova. It shows the inner core of R Aquarii, resolved into two very bright knots of emission separated by about 0.8 arcsec, surrounded by faint circular structures due to the spherical aberration. The two knots, probably harbouring the binary system, show up as dark spots in the photograph due to saturation effects produced by the detector when it observes very bright objects.

The fascinating aspect of this image is the linear filamentary features clearly seen emanating from the core. These are especially prominent above the core but fainter lines can be discerned below it. This is clearly plasma that has been ejected at high speeds from the 'reactor' and bathed in high-energy radiation emitted since the time of the eruption. The plasma emerges geyser-like in streams twisted by the force of the explosion and channelled upwards and outwards by strong magnetic fields. An obstruction in the path of the flowing material can also be discerned in the upper part of the image, where the material is forced to bend back on itself in a spiral pattern.

The scale of the event is extraordinary even in astronomical terms, since emitting material can be traced out to at least 400 billion km (2500 times the distance between the Sun and the Earth) from the central core. Images such as these are expected to revolutionise our ideas about such stellar 'volcanoes' as R Aquarii and shed increasing light on how nature redistributes the products of nuclear burning from deep inside stars and back into the Universe.



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Pluto, the 'double planet'
Pluto is our Solar System's most distant and enigmatic object. The ninth and last real planet known, and the only planet that has not been visited by a fly-by spacecraft, Pluto was discovered just 60 years ago by the American astronomer Clyde Tombaugh, who was searching for the source of irregularities seen in the orbits of Uranus and Neptune.

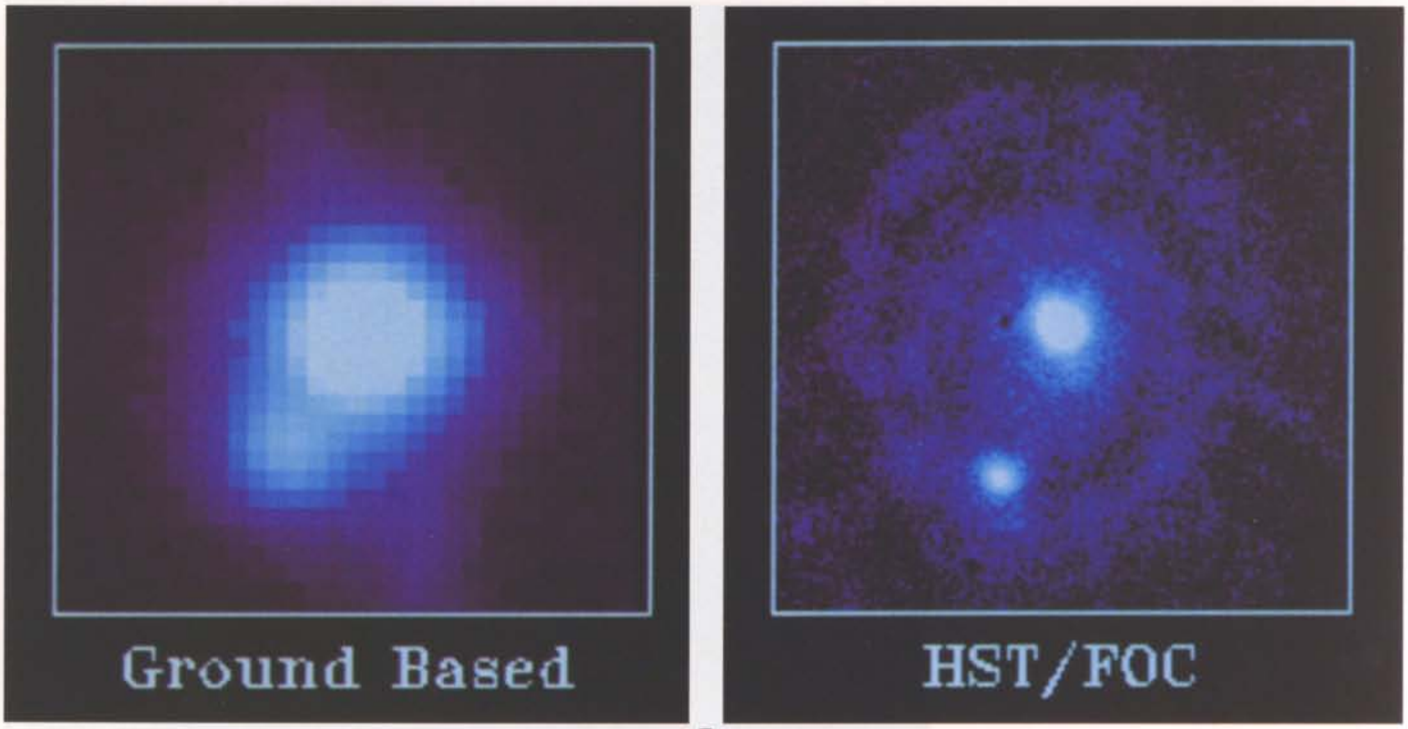
It has since become apparent that Pluto is a very peculiar object. Its orbit is tilted and is more elliptical than that of any of other planet in the Solar System. Pluto also rotates upside down with its North Pole below the plane of the Solar System, unlike most of the other planets.

Pluto is smaller than our own Moon and denser than any of its neighbours in the outer Solar System. But, perhaps its most fascinating property was uncovered only 12 years ago when a huge companion 'moon' called Charon was detected from ground-based photographs. Subsequent investigations have shown that Charon is about half the size of Pluto, making it the largest known satellite relative to its planet in the Solar System. Because of this, Pluto is often referred to as a double planet. The rotation period of the Pluto-Charon system is a mere six days.

A recent FOC image of Pluto and Charon is shown in Figure 5 (upper right). This image is the first long-duration HST exposure ever taken of a moving target. In order to avoid smearing of the images, ground controllers had to pre-programme the HST spacecraft to track Pluto extremely accurately and to compensate exactly for the 'parallax' introduced by the combined motions of Pluto, the Earth and HST in their respective orbits.

Pluto is currently near its closest approach to the Earth in its 249-year journey around the Sun, and is approximately 4.5 billion kilometres away. The bright object at the centre of the frame is Pluto, while Charon is the fainter object in the lower left. Charon is fainter than Pluto because it is smaller and, probably, because its surface is covered by water ice, whereas Pluto is thought to be covered mainly by the more reflective methane frost or snow.

As shown diagrammatically in the lower part of Figure 5, Charon's orbit around Pluto is a circle seen nearly edge on



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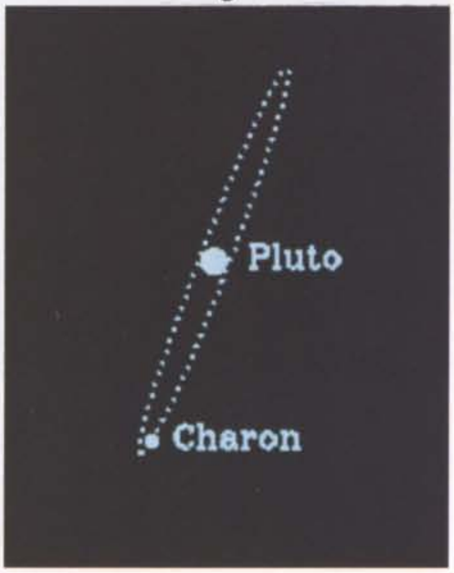


from Earth, with a radius of almost twenty thousand kilometres (approximately one-and-a-half times the diameter of the Earth). At the time of observation, Charon was near its maximum apparent distance from Pluto, so that its angular separation was about nine tenths of an arcsecond. Because of the peculiar orientation of the Pluto–Charon orbit with respect to our line-of-sight, Charon approaches to within less than one tenth of an arcsecond of Pluto every three days.

Due to the physical proximity of the two planets and the great distance from Earth, it is extremely difficult to clearly resolve the pair with a ground-based telescope except in exceptional circumstances. The best ground-based image of Pluto and Charon ever taken to date is shown in the upper left frame of Figure 5. This image was taken with the Canada-France-Hawaii telescope in Hawaii. The superior resolution of the FOC image is evident.

Further HST observations of Pluto and Charon will be extremely important in elucidating the nature and the origin of this fascinating and frigid world where the average temperature approaches −215°C (only 58° above absolute zero). Although the 'fog' caused by the spherical aberration of the primary mirror prevents the FOC from resolving surface features, several other critical pieces of information can be extracted from continuing FOC observations of these objects.

Detailed analysis of the brightness variations of the two planets will provide a wealth of information on their surfaces and atmospheres that is impossible to obtain from the ground. Precise measurements of the orbital parameters of the Pluto-Charon system are now also possible. This will enable astronomers to measure the individual masses and densities of the two objects, thereby providing important clues as to their origins.

One possibility is that objects similar to Pluto and Charon were created in great numbers in the outer fringes of the primordial solar nebula, but the majority of these 'planetary embryos' were either expelled from the inner Solar System or swallowed up by the giant planets Jupiter, Saturn, Uranus, and Neptune. Only Pluto and Charon survived independently.

Continued monitoring of these two fascinating objects at the outer edge of our Solar System throughout the lifetime of HST will help astronomers understand the nebula from which we were all originally formed.

The ESA FOC Commissioning Team

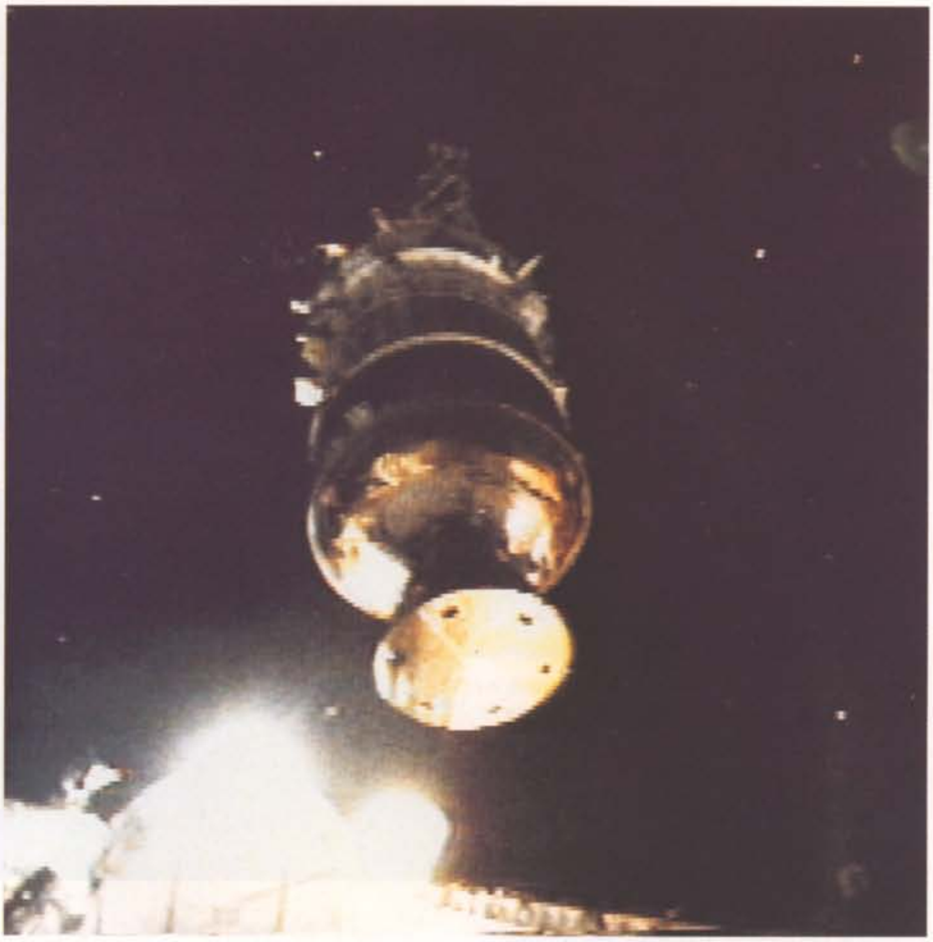
Ulysses Successfully Launched from Space Shuttle Discovery

With the successful launch of the Space Shuttle Discovery on Saturday 6 October, ESA's deep-space probe Ulysses began its long-awaited journey to the polar regions of the Sun. Discovery lifted off at 11:47 GMT, only 12 min after the opening of the 2½-hour launch window on the second day of the 18-day launch period. Ulysses was deployed from Discovery's cargo bay at 17:48 GMT, and ignition of the first of the three upper-stage motors occurred 65 min later, sending the spacecraft on its way to Jupiter, the first port of call on its five-year odyssey.

Ulysses will be the first spacecraft ever to explore the region of space above and below the poles of the Sun, and its scientific mission is to investigate how the Sun's environment, the heliosphere, changes with increasing solar latitude. The scientific payload comprises nine instrument packages that will make measurements of the solar wind, the heliospheric magnetic field, solar energetic particles and galactic cosmic rays, radio bursts and plasma waves, solar X-rays, cosmic gamma bursts, interstellar neutral gas and cosmic dust. In order to provide a comprehensive map of the inner heliosphere at all latitudes, the instruments will operate continuously throughout the mission, collecting data 24 hours a day.

The Jupiter encounter will take place in February 1992, at which time the gravitational attraction of the giant planet will pull the spacecraft out of the ecliptic (the plane in which the Earth and most of the planets move around the Sun) into an orbit that will take it over both solar poles before its mission ends in 1995. During the high-latitude phase of the mission, Ulysses will spend a total of 235 days above 70° solar latitude, reaching a maximum latitude of 80.2°.

Originally scheduled for launch in February 1983, the fate of the Ulysses mission has been inexorably tied to that of the Shuttle programme. In particular, the aftermath of the 1986 Challenger accident added a further 4½ years to the already much-delayed project. The 'nearly flawless' STS-41 mission that finally launched Ulysses on its way on



Ulysses is deployed from the Space Shuttle Discovery (video still, courtesy NASA)

6 October was an understandably emotional event for the many scientists and engineers who have worked for more than 12 years on the project.

At the time of writing, the checkout of the scientific payload is well underway, with six of the nine experiments switched on and working nominally. One of these, the Low-Energy Telescope of the Cosmic Ray and Solar Particle Experiment, was designed and built by the Solar and Heliospheric Science Division of ESA's Space Science Department.

Other experiments already collecting valuable scientific data include the Interstellar Neutral Gas instrument, which has achieved the first-ever direct detection of interstellar neutral helium atoms, and the Magnetic Field and Radio/Plasma Wave instruments. The commissioning activities for the latter included the successful deployment of the 72.5 m (tip-to-tip) wire boom and the 7.5 m axial boom antennas. Preliminary data from both magnetometers clearly show that Ulysses is the most magnetically clean spacecraft ever flown, demonstrating that the painstaking control of magnetic contamination throughout the long testing programme has paid off.

Spacecraft operations are being conducted from NASA's Jet Propulsion Laboratory (JPL) in Pasadena by a resident team of ESOC engineers, supported by JPL institutional staff. Two of the three planned Trajectory Correction Manoeuvres have been carried out to refine the targeting for the Jupiter encounter and, with the exception of an as yet unexplained nutation build-up following deployment of the axial boom, all spacecraft subsystems are functioning nominally.

Travelling at close to 145 000 km/h with respect to the Sun, Ulysses was over 30 million km from Earth on 9 November, with 780 million km still to go before reaching Jupiter on 8 February 1992, where it will be 'launched' into its final out-of-ecliptic orbit.

R. Marsden
Ulysses Project Scientist
ESA Space Science Department

New ESA Satellite Station in Sweden

His Majesty the King of Sweden inaugurated ESA's Salmijärvi Satellite Station on 6 September. Located near Kiruna in northern Sweden, the Salmijärvi station has been built primarily to support the European Remote-Sensing Satellite, ERS-1, scheduled for launch in April 1991.

The King and Queen were welcomed by Prof. Lüst and addresses were given by Mr O. Rydh, Under Secretary of State at the Swedish Ministry of Industry, Prof. K. Fredga, Director General of the Swedish National Space Board and Mr L. Essling, Mayor of Kiruna.

The Managing Director of the Swedish Space Corporation, Dr L. Lübeck, gave a history of the Salmijärvi site. ESA's Director of Observation of the Earth and its Environment, Mr P. Goldsmith, then gave a presentation on the ERS satellite, and Mr K. Heftman, Director of Operations, described station operations.

After the ceremony, the royal party was given a tour of the station, including a demonstration of spacecraft tracking and data-processing operations.

His Majesty King Gustav presses the button to inaugurate ESA's Salmijärvi Satellite Station (6 September 1990)

Huygens Instruments Selected

At its meeting of 17/18 September, the Agency's Science Programme Committee (SPC) approved the selection of the payload for the Huygens Probe (see Table 1).

The SPC also recommended that ESA and NASA try to accommodate two other instruments: a nephelometer (possibly a refurbished Galileo instrument), to measure cloud aerosol size and distribution, and an altimeter (provided by ESA) to measure height above the ground during the Probe's descent and provide data on surface roughness.

The SPC also appointed three interdisciplinary scientists: D. Gautier (F) for Titan aeronomy, J.I. Lutine (US) for atmosphere/surface interactions and F. Raulin (F) for Titan organic chemistry.

The Cassini spacecraft is scheduled to be launched by NASA in 1996, with the ESA probe landing on Titan in 2002.

Table 1. ESA's contribution to the Cassini mission

Instrument	Purpose	Principal Investigator
Atmospheric Structure Instrument (ASI)	To measure the temperature and pressure of Titan's atmosphere, winds and turbulence, and the atmospheric electricity	M. Fulchignoni (I)
Gas Chromatograph and Neutral Mass Spectrometer (GCNMS)	To measure the composition of Titan's atmosphere during descent	H. Niemann (US)
Aerosol Collector and Pyroliser (ACP)	To collect aerosols suspended in the atmosphere and analyse their composition	G. Israel (F)
Descent Imager/Spectral Radiometer (DISR)	To make spectral measurements in several wavelengths from the UV to the near-infrared, and photograph the clouds and surface of Titan	M. Tomasko (US)
Surface Science Package (SSP)	To provide information on the state of Titan's surface (liquid, solid, etc.) at the point of touchdown	J. Zarnecki (UK)
Doppler Wind Experiment (DWE)	To measure zonal wind characteristics with a very high accuracy	M. Bird (D)

Signature of the ISO Final Contract

Signing of the ISO Final Contract at ESA Headquarters on 13 September. Seated: Mr H. Martre (left), President and Director General of Aerospatiale and Prof. R. Lüst, ESA's Director General; background: Mr G. Leroy (left), Director of Information and Communication in the Space and Strategic Systems Division of Aerospatiale and Mr M. Herbert, ISO Contracts Officer, Aerospatiale

On 13 September ESA's outgoing Director General, Prof. R. Lüst, and Mr H. Martre, President and Director General of Aerospatiale, signed the Final Contract for the development, manufacturing, integration and testing of the Infrared Space Observatory (ISO).

The Development Phase has already been underway since March 1988, with Aerospatiale as Prime Contractor leading a European Consortium of 35 space firms, the major ones being CASA (E), ETCA (B), Fokker (NL), Laben (I), Marconi (UK), MBB (D) and Selenia (I).

ISO, due for launch by Ariane in 1993, will provide astronomers with an unique facility of unprecedented sensitivity for detailed exploration of the Universe. Operating at wavelengths from 2.5 to 200 micron, it will be able to study objects in the solar system right out to the most distant extra-galactic sources.

First International Symposium on Ground Data Systems for Spacecraft Control

The First International Symposium on Ground Data Systems for Spacecraft Control, sponsored by ESA, was held in Darmstadt, Germany, between 26–29 June 1990. Organised by the Data Processing Division of the Agency's Computer Department, the Symposium was attended by approximately 350 participants, many of whom were from the major space agencies and leading aerospace and software companies.

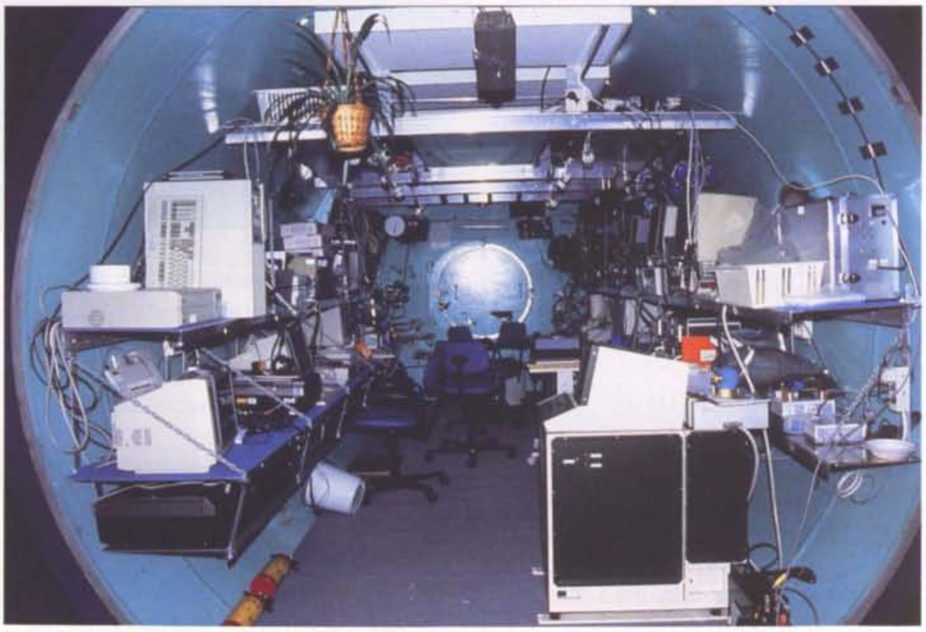
All major aspects of spacecraft control systems were covered: architectures, station control and ground communications, mission management, user requirements, influence of evolving on-board technology, knowledge-based systems, man/machine interfaces, safety, reliability, security and telescience. Each of the parallel sessions commenced with a keynote address reviewing the state-of-the-art and identifying the main problem areas.

It became obvious during the Symposium that many of the agencies present were experiencing similar problems and that there was often a common approach to tackling them. One concrete result of the meeting should therefore be the fostering of better cooperation and a consequent reduction in the current duplication of effort. Cooperation would be greatly assisted by greater standardisation among the various organisations.

M. Jones & C. Mazza
Data Processing Division, ESOC

The First International Symposium on Ground Data Systems for Spacecraft Control, Darmstadt, Germany, 26–29 June 1990

The Isolation Study for the European Manned Space Infrastructure (ISEMSI)



After four weeks underwater, six men emerged on 15 October from the hyperbaric chambers of the Norwegian Underwater Technology Centre (NUTEC) at Ytre Latsevag near Bergen.

Like the Antarctic crossing (see pages 44-49 of this issue), this experiment is one of a series conceived by the Long-Term Programme Office of the Agency's Directorate of Space Station and Microgravity to investigate the effect on Man of long-duration space missions. Support was provided by the Technical Directorate at ESTEC, the European Astronauts' Centre (EAC) in Cologne and the Columbus Project team.

The aim of the Isolation Study for the European Manned Space Infrastructure (ISEMSI) is to investigate group performance and interaction during a long period of isolation, analogous to conditions in space. During their four weeks underwater, the six scientists and engineers carried out operational and research tasks as they would aboard a space station.

The hyperbaric chambers at the Norwegian Underwater Technology Centre (NUTEC) (upper photo)

The working area inside the NUTEC hyperbaric chamber (lower photo)

ESTEC's In-Orbit Servicing Centre

With the Large Acoustic Test Facility (LEAF) and the Compact Payload Test Range (CPTR) only just opened, building has already begun at ESTEC of a new complex, the In-Orbit Servicing (IOS) Centre. During his farewell visit to ESTEC on 19 September, the outgoing Director General Prof. R. Lüst sank the 'first pile' of the new building.

The Centre, due for completion by the end of January 1992, will provide the ground facilities for robotic training and an engineering support centre for in-orbit servicing. There will also be room to host the astronauts undergoing training.

In addition to the robotics laboratory, the facilities will include a 1-g three-dimensional manipulator, Eurosim, the Crew Work Station test bed and the associated simulation and electrical facilities laboratory, together with 3000 m² of office space, mainly intended for the Automation and Informatics Department.

Prof. R. Lüst sinks the 'first pile' of the new In-orbit Servicing (IOS) Centre at ESTEC, Noordwijk (19 September 1990)

First Results from Biokosmos-9

Scientists in the ESA Member States and the Soviet Union have just released the first results of the Biokosmos-9 life sciences experiments. The Soviet space biology mission, which lasted two weeks in September 1989, was organised by the Institute of Biomedical Problems in Moscow and carried five ESA experiments (see ESA Bulletin No. 60, p. 70). This was the second such cooperative venture, the first being in October 1987, when two ESA experiments were launched aboard Biokosmos-8.

First results confirmed observations made on the Biokosmos-8 mission and aboard Spacelab D1, namely that microgravity does influence the functioning of biological cells, but also revealed new information, in turn posing new questions.

In earlier experiments scientists had observed that the stick insect, Carausius morosus, evolved differently under microgravity conditions. The insect normally takes between 80 and 100 days to develop from an egg to a fully developed young larva. Eggs at five different stages of development had been exposed to microgravity for seven days and then allowed to develop further on the ground. A striking result of these earlier experiments was that only 50% of the stage-2 eggs hatched, whereas eggs exposed to microgravity at other stages of development were unaffected.

On Biokosmos-9, despite their inability to hatch, the larvae from the stage-2 eggs developed into normal-looking insects. This implies that some stage of the development process (probably short duration) is gravity-dependent, affecting the functional abilities of the fully-developed larvae. This raises several questions: Which stage of embryonic development is sensitive to the absence of gravity and why? How does this affect the embryo?

Putting the fruit flies into 'late access' box on Biokosmos-9

Similar results had been found earlier with fruit flies, where hatching of 50% of the eggs laid in space was inhibited. During the Biokosmos-9 mission fruit flies were conceived and matured in space, completing an entire life cycle in microgravity. These flies appeared much retarded compared to the control flies on the ground. It took a week longer than normal for the adult flies to emerge from the pupae. The males raised in space were less active and had a shorter life span than the control males. Since the larvae also feed on eggs, it was not possible to determine the percentage of eggs hatched but, as in the Spacelab D1 mission, the number of offspring recovered from space was much higher than on the ground, which confirmed the earlier observation that many more eggs are laid in microgravity conditions.

ESA at the IAF

A high-level ESA delegation, led by Mr J-M. Luton, the Agency's Director General, attended the 41st Congress of the International Astronautical Federation (IAF) held in Dresden, 8 – 12 October.

Mr Luton chaired the Congress' Symposium on International Space Plans and Policies, while other members of ESA's senior management chaired sessions and made formal presentations. Only five days after the Unification of Germany, this provided an ideal opportunity to discuss the role of the new German states in future European space activities.

The Agency also participated in the 'Space 90' exhibition held at the Dresden Exhibition Hall in parallel with the IAF Congress. Models on display included the Ulysses space probe, Ariane, the Hermes spaceplane and Columbus.

A special facility was set up to deliver television programmes to the Congress via ESA's Olympus satellite and to enable the press and Congress participants to send electronic mail from Dresden.

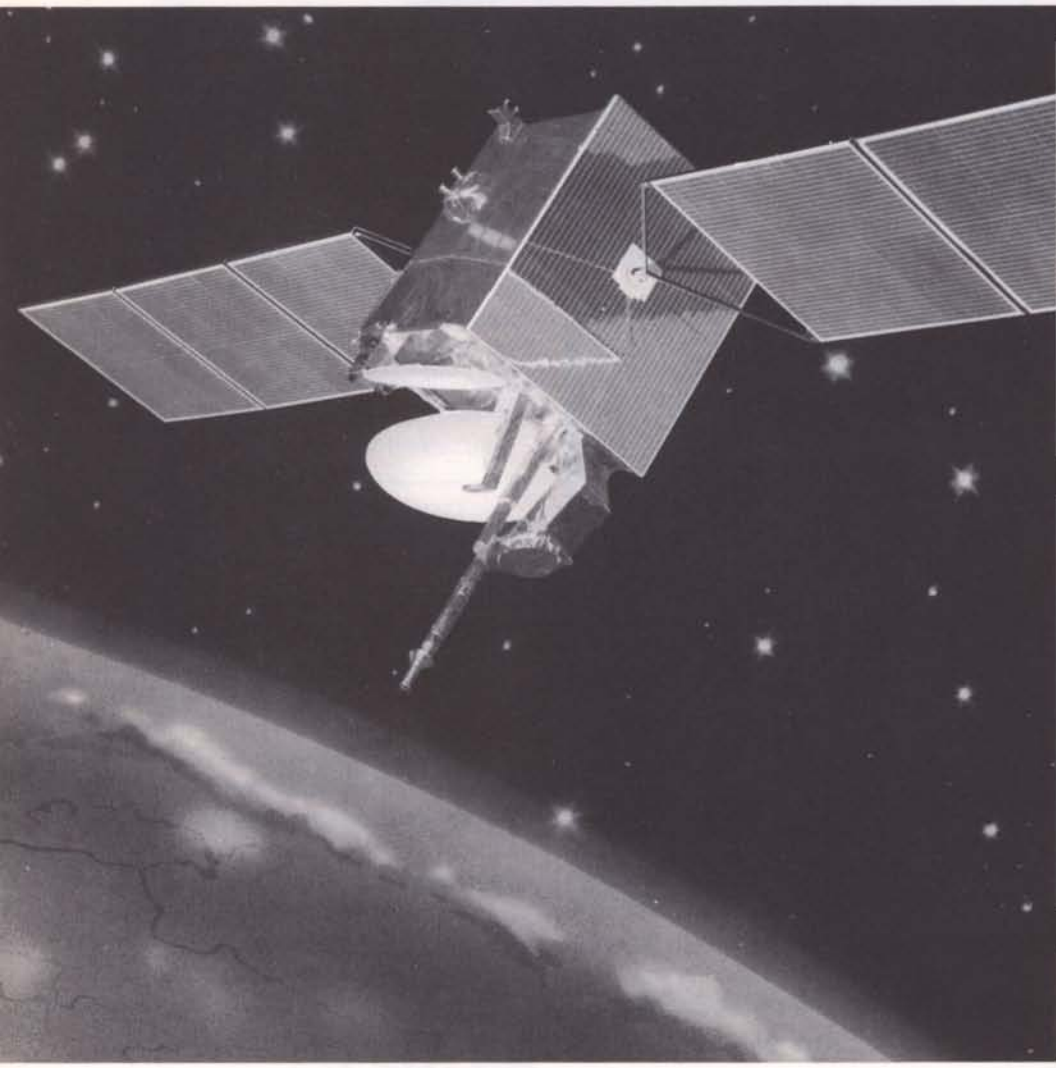
Two More Successes for Ariane

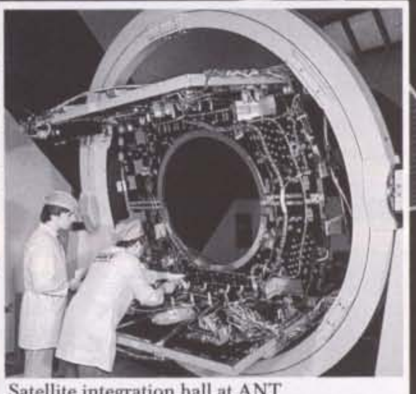
On the night of Friday 12 October at 21:58 hours Universal Time (UT) the 11th Ariane-4 launcher (V39) carried into orbit the two telecommunications satellites SBS-6 and Galaxy VI for Hughes Communications Inc. After a smooth flight the two passengers were successfully injected into Geostationary Transfer Orbit.

This was the third flawless launch of Ariane following the disappointment of the failure of V36 in February. Six weeks earlier, on 30 August at 22:46 hours UT time Ariane V38 lifted off from the ELA-2 launch pad in Kourou, French Guiana. The Ariane 44 LP launch vehicle placed its two passengers, Eutelsat II F1 and Skynet 4C into a very precise Geostationary Transfer Orbit.

Satellite Technology from ANT:

DFS Kopernikus – The German Telecommunications Satellite





Satellite integration hall at ANT

DFS antenna module measurement

DFS Kopernikus, the first German telecommunications satellite, has gone into orbit. The satellite programme was designed and manufactured by the ANT/MBB consortium. The system consists of two spacecraft and a ground spare. ANT supplies the entire telecommunications payload.

Kopernikus is equipped with eleven transponders which can be simultaneously operated for the transmission of speech, text, data and TV programmes in the 11/14, 12/14 and 20/30 GHz frequency ranges. Six further transponders are mounted onto the satellite for redundancy operation.

Furthermore, ANT supplied the receiver systems for 32 small DFS earth stations and was the main contractor for the 11/14 GHz DFS earth station in Berlin as well as for the conversion to DFS operation of an earth station in Usingen.

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Programmes under Development and Operations / Programmes en cours de réalisation et d'exploitation

In Orbit / En orbite

	PROJECT	1990 1991 1992 1993 1994 1995 1996	COMMENTS
SCIENT. PROG.	IUE		
	HIPPARCOS		OPERATIONAL 3 YEARS
APPLICATIONS PROGRAMME	MARECS-A		LEASED TO INMARSAT FOR 10 YEARS
	MARECS-B2		LEASED TO INMARSAT FOR 10 YEARS
	METEOSAT-3		LIFETIME 3 YEARS
	METEOSAT-4 (MOP-1)		LIFETIME 5 YEARS
	ECS-1		LIFETIME 7 YEARS
	ECS-2		LIFETIME 7 YEARS
	ECS-4		LIFETIME 7 YEARS
	ECS-5		LIFETIME 7 YEARS
	OLYMPUS-1		LAUNCHED 12 JULY 1989

Under Development / En cours de réalisation

	PROJECT	1990 1991 1992 1993 1994 1995 1996	COMMENTS
SCIENTIFIC PROGRAMME	SPACE TELESCOPE		LAUNCHED APRIL 1990
	ULYSSES		LAUNCHED OCTOBER 1990
	SOLAR TERRESTRIAL SCIENCE PROG. (STSP)	SOHO CLUSTER	LAUNCHES SOHO JULY 1995 CLUSTER DEC. 1995
	ISO		LIFETIME 1.5 YEARS
	HUYGENS		TITAN DESCENT DEC. 2002
COMMS. PROG.	DATA-RELAY SATELLITE (DRS)	PHASE-1 PHASE-2	SYSTEM OPERATIONAL 1996
	ARTEMIS		READY FOR LAUNCH MID-1994
EARTH OBSERV. & MICROGRAVITY PROGRAMMES	ERS-1		
	ERS-2		LAUNCH 1994
	EARTH OBS. PREPAR. PROG. (EOPP)		
	METEOSAT OPS.PROG.	MOP-2 MOP-3	MOP-2 LAUNCH DATE UNDER REVIEW
	MICROGRAVITY	IML-1 EURECA D2 IML-2	
SPACE ST. & PLATF. PROG.	EURECA		READY FOR LAUNCH DEC. 1991
	COLUMBUS	PHASE-1 PHASE-2	3 YEAR INITIAL DEVELOPMENT PHASE
SPACE TRANSPORT. PROG.	ARIANE-4	V35/36 V37/38 V39/40	
	ARIANE-5		FIRST FLIGHT APRIL 1995
	HERMES		3 YEAR INITIAL DEVELOPMENT PHASE
TECH. PROG.	IN-ORBIT TECHNOL. DEMO. PROG. (PH-1)		SEVERAL DIFFERENT CARRIERS USED

= DEFINITION PHASE; > PREPARATORY PHASE; ▨ MAIN DEVELOPMENT PHASE; * STORAGE; HARDWARE DELIVERIES
~ INTEGRATION; LAUNCH/READY FOR LAUNCH; • OPERATIONS; - ADDITIONAL LIFE POSSIBLE; RETRIEVAL

Olympus

Le satellite Olympus-1 est arrivé à la fin de sa première année de vie en orbite le 12 juillet dernier. Les quatre charges utiles continuent de fonctionner normalement et sont de plus en plus utilisées par des organisations très diverses.

Le centre de contrôle des opérations de Fucino, en Italie, assure sans problème la conduite des opérations.

La charge utile de télédiffusion directe suscite un intérêt croissant. Trois nouveaux utilisateurs y auront accès à compter du mois d'octobre. Le multiplexage numérique du signal D-MAC pour la transmission de données fait également l'objet d'un intérêt de plus en plus soutenu. La BBC procède à des essais de transmission de données en utilisant l'intervalle de suppression de trame pour les émissions Eurostep.

La charge utile des services spécialisés a aussi permis diverses utilisations intéressantes. Lors d'une téléconférence organisée en juin par IBM, les interventions des conférenciers étaient transmises de Bruxelles à douze sites d'IBM en Europe, ainsi que les réponses aux questions posées à distance. La station terrienne transportable TDS-4 de l'ESA a également été mise à contribution pour la liaison montante lors d'une téléconférence de formation au management à Saint-Sébastien.

La charge utile 20/30 GHz continue d'être utilisée pour les expériences CODE (Expérience en coopération sur les données d'Olympus) et DICE (Expérience de commutations directes inter-établissements). CODE, qui permet à des terminaux de très petite ouverture (VSAT) d'échanger des données avec une station centrale, a fait l'objet d'une démonstration satisfaisante dans une configuration à quatre points, l'ESTEC étant le moyeu. Les installations de visioconférence DICE, qui utilisent des liaisons vidéo/phonie et des données d'excellente qualité, ont permis une démonstration probante dans le cadre d'une configuration à trois points.

Le programme de référence Olympus comprenait un jeu complet d'équipements destinés à un satellite de secours en cas d'échec du lancement ou de la mise sur orbite d'Olympus-1. Lorsqu' il a été clair que celui-ci fonctionnait normalement, les Etats membres ont donné leur accord pour que ces équipements soient utilisés à d'autres fins. Des propositions de missions communes avec des organismes extérieurs ont été sollicitées et plusieurs organisations ont marqué un vif intérêt pour l'utilisation de ce matériel. Ces missions communes font maintenant l'objet d'études au plan industriel, l'objectif étant de proposer une mission Olympus-2 d'ici à la fin de cette année.

Ulysse

La campagne de lancement d'Ulysse a démarré à la date prévue. Le 17 mai, la sonde (370 kg) ainsi que 58 tonnes d'équipement ont été acheminées vers le Centre spatial Kennedy par un Boeing 747 affrêté auprès d'Air France. L'ensemble a été transféré dans un centre de montage des charges utiles pour l'assemblage des éléments définitifs et la vérification générale du véhicule spatial. Les essais de compatibilité avec le réseau de l'espace lointain (DSN), le centre des opérations du JPL à Pasadena, et le générateur thermo-électrique à radio-isotopes qui fournira l'énergie pendant toute la durée de la mission, ont donné toute satisfaction. A l'issue de ces travaux, qui ont duré environ six semaines, le véhicule spatial a été transféré dans un centre de manipulation des produits dangereux pour le remplissage des réservoirs; l'ergol utilisé (environ 33 kg d'hydrazine) fournira au système de commande d'orientation et de modification d'orbite l'énergie nécessaire pendant les cinq années que durera la mission.

Dans un même temps, le reste de la charge utile de la Navette, à savoir l'étage supérieur inertiel (IUS) et le PAM-S chargés de mettre la sonde sur sa trajectoire interplanétaire, était en cours d'intégration dans d'autres installations du Centre spatial Kennedy. A la mi-juillet, les trois unités ont été assemblées verticalement et soumises à des essais destinés à vérifier qu'elles étaient compatibles entre elles et avec l'orbiteur. Le 24 août, tous les éléments étaient déclarés prêts au lancement et embarqués dans le conteneur à destination du pas de tir en vue de leur installation dans Discovery.

La configuration de la station sol chargée de la conduite des opérations après le lancement est achevée. Tous les logiciels ont été soigneusement vérifiés et figés. Pour optimiser les techniques de télécommunications de cette mission très complexe, il a été procédé à des simulations de chronologie du lancement et du largage de la sonde, qui se sont déroulées de manière satisfaisante. Le responsable des opérations de la mission est convaincu que le personnel, le matériel et le logiciel sont prêts pour le lancement (les informations de dernière date relatives au lancement figurent à la page 109).

STSP

Soho

La phase B se déroule sous la conduite de Matra, conformément au calendrier prévu et sans difficultés majeures.

La revue des impératifs du système, qui s'est tenue en mai avec le soutien de la NASA, a donné toute satisfaction. Seules les marges retenues lors de la conception du module de la charge utile pour faire face à une évolution des caractéristiques de puissance ont inspiré quelques préoccupations. Cette configuration a été légèrement modifiée de manière à prévoir des marges suffisantes pour répondre aux impératifs de pointage de la charge utile et aux contraintes structurelles/thermiques.

La demande de prix de la phase C/D a été envoyée le 7 septembre. Les propositions de l'industrie sont à remettre au plus tard le 30 novembre pour que la phase C/D puisse débuter le 15 avril 1991.

Le véhicule spatial, dont la masse au lancement de 1850 kg est maintenant officiellement approuvée par la NASA, sera lancé du Centre spatial Kennedy (KSC) par un lanceur ATLAS-IIAS de la NASA. Celle-ci dirigera les opérations de vol à partir d'un centre de contrôle du Centre spatial Goddard (GSFC). La coopération avec la NASA progresse normalement et la participation de l'Agence américaine à cette mission se déroule sans difficultés majeures.

La structure industrielle du projet Soho, de même que celle du projet Cluster, a été mise au point avec soin afin qu'un

Olympus

The Olympus-1 satellite completed its first year in orbit on 12 July. All four payloads have continued to operate well and are being used more and more extensively by a wide range of organisations.

Control of the satellite has continued to proceed smoothly from the operations control centre at Fucino in Italy.

Interest in the use of the Direct-Broadcast payload continues to grow. Three more users will be accessing the payload from October onwards. Interest is growing in the use of the digital multiplexing of the D-MAC signal to transmit data. The British Broadcasting Corporation (BBC) is experimenting with data-transmission trials, using the vertical-blanking interval on the Eurostep broadcast transmissions.

The Specialised-Services payload has also been used for a variety of interesting events. Invited lectures given at an IBM teleseminar in Brussels in June were transmitted to twelve IBM sites throughout Europe, with opportunity for questions from these remote locations. In another application live coverage of a management-training conference at San Sebastian was provided, using ESA's TDS-4 transportable earth station for the uplink.

The 20/30 GHz payload has continued to be used for the Cooperative Olympus Data Experiment (CODE) and Direct Inter-Establishment Experiment (DICE) tests. CODE, which allows Very-Small-Aperture Terminals (VSATs) to exchange data with a hub station, has been successfully demonstrated in a four-point configuration with ESTEC as the hub station. The DICE video-conference facilities, using high-quality video/sound and data, have been successfully demonstrated in a three-party configuration.

The baseline Olympus Programme included a complete set of equipment for a back-up spacecraft in the event of a launch or early in-orbit failure of Olympus-1. When it became clear that Olympus-1 was operating successfully, the Member States gave permission to seek alternative uses for this back-up equipment. Proposals for joint missions with outside Agencies were invited and considerable interest has been expressed by several organisations. Industrial studies of these joint missions are now being performed with the aim of proposing a mission for Olympus-F2 by the end of this year.

Ulysses

The Ulysses' launch campaign began on 17 May, as planned, with the shipment of 58 tons of equipment plus the 370 kg flight spacecraft to Kennedy Space Center (KSC) on a chartered Air France 747. The equipment was all transferred to a Payload Processing Facility where the final units were installed and a complete check of the spacecraft made. Compatibility tests with the Deep Space Network, the Operations Centre based in the Jet Propulsion Laboratory (JPL), Pasadena, and the Radioisotope Thermoelectric Generator, which will provide power throughout the mission, were successfully made. This activity lasted about six weeks, after which the spacecraft was transported to a Hazardous Processing Facility where it was loaded with some 33 kg of hydrazine, the fuel used for the attitude-and-orbit-control system during its five-year lifetime.

In parallel, the remainder of the Shuttle payload, namely the Inertial Upper Stage and the PAM-S which jointly form the interplanetary injection vehicle, was being integrated in other facilities within KSC. In mid-July the three units were brought together in the Vertical Processing Facility where they were mated and a number of tests performed to demonstrate their compatibility with each other and with the Orbiter. On 24 August the complete stack was declared ready and put into the canister for transportation to the launch pad to be mated with the Orbiter 'Discovery'.

The ground station from which the spacecraft will be controlled after launch is now completely ready, with all necessary software thoroughly checked out and frozen. A number of simulated launch and deployment countdowns have been held in order to perfect the communication techniques for this very complex mission. These have been very successful and the Mission Operations Manager is convinced that the manpower, hardware and software are all ready for launch (for latest launch information see page 109).

STSP

Soho

Phase-B, with Matra as the Prime Contractor, is proceeding on schedule and without any major problems.

The System Requirements Review, supported also by NASA, took place in May. The only item of concern was the marginality of payload module design in

Ulysses vue de la navette Discovery

Ulysses seen from the Shuttle Discovery

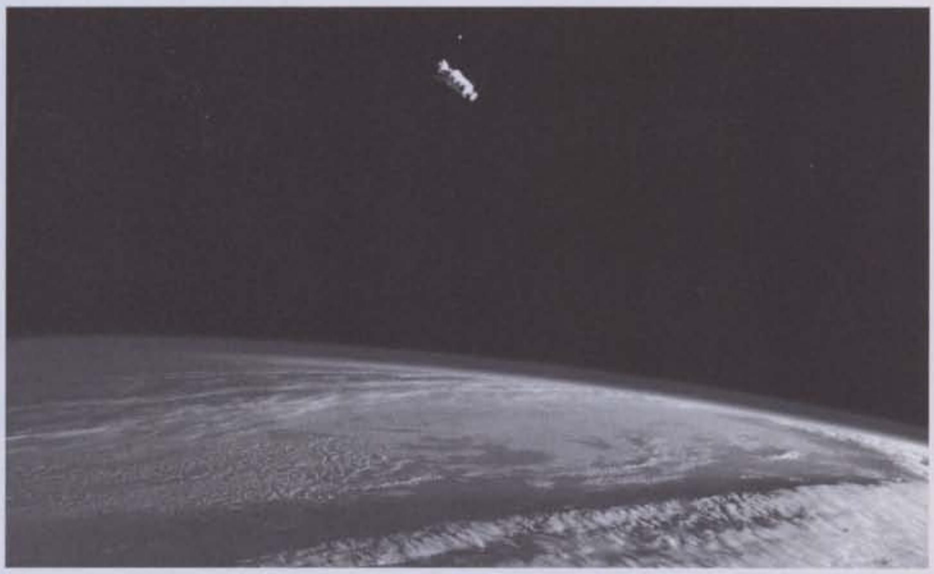


Photo: NASA

équilibre acceptable soit préservé entre le retour géographique, le coût et les performances techniques. Tous les contractants des sous-systèmes ont reçu le feu vert. Les propositions relatives aux unités et sous-systèmes parviennent actuellement à l'Agence et seront intégrées, après recette en bonne et due forme par l'ESA et par Matra, à la proposition de phase industrielle C/D.

La revue de conception du système, qui constituera la prochaine étape, aura lieu en mars 1991. D'ici là, le Comité de la politique scientifique (SPC) et le Comité de la politique industrielle (IPC) devront approuver la mise en oeuvre de la phase C/D, y compris pour le projet Cluster.

Les travaux relatifs à la charge utile Soho ont bien progressé. La définition des interfaces des expériences a considérablement avancé et tous les documents s'y rapportant ont été mis à jour préalablement à la mise en route de la phase B afin que la définition et la conception du système puissent démarrer sur des bases claires.

Les prochaines étapes à franchir pour le projet Soho seront la prochaine réunion du groupe de travail scientifique et la remise de la proposition de phase C/D par Matra, qui auront lieu toutes deux vers la fin novembre.

Cluster

Pendant la phase B-2 du projet qui s'est achevée le 15 septembre, conformément au calendrier, un consortium industriel a été mis sur pied et les principaux contractants des sous-systèmes ont remis au maître d'oeuvre des propositions de phase C/D.

Le maître d'oeuvre devait remettre sa proposition globale de phase C/D à l'Agence avant le 15 octobre. Il est prévu de terminer l'évaluation d'ici fin novembre, de manière à pouvoir démarrer la phase C/D en février 1991 conformément aux prévisions.

Les activités actuelles de phase B-3 sont axées sur la conception détaillée des sous-systèmes, l'objectif étant d'obtenir en temps voulu les pièces et les matériaux à long délai de livraison. Parallèlement, un certain nombre de contrats de sous-traitance ont été passés pour des activités anticipées de phase C/D, notamment pour la commande de matériel critique et le lancement des activités de mise au point des sous-systèmes, ce qui devrait permettre de respecter le calendrier de réalisation du modèle structurel dont l'intégration doit commencer à la mi-octobre 1991.

Au cours de cette phase B-3, il est prévu d'exécuter les revues de conception des sous-systèmes avec tous les sous-traitants avant de remettre à l'Agence, à la mi-décembre, le dossier de revue de conception du système. L'achèvement de la revue de conception du système marque officiellement la fin de la phase B.

Parallèlement aux travaux actuels de phase B-3, on procède à des revues de conception intermédiaires avec tous les expérimentateurs intéressés, afin de figer la conception de la charge utile pour la revue de conception du système. La 5ème réunion du groupe de travail scientifique Cluster est prévue fin novembre.

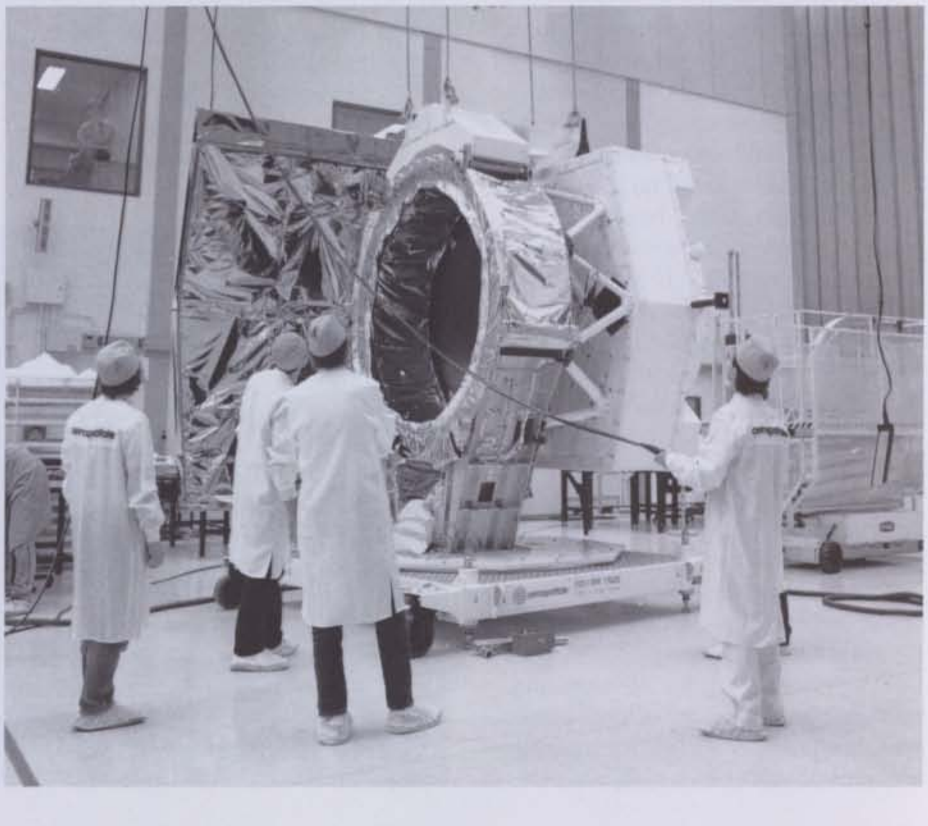
L'offre de participation relative au système de données scientifiques de Cluster a été lancée dans les délais prévus, une réponse étant demandée pour la fin décembre. De nombreux organismes dépendant de pays non membres de l'ESA ont manifesté leur intérêt et des études sont en cours pour leur permettre de participer au système décentralisé.

La conception du secteur sol de Cluster suit son cours. Une revue des impératifs devrait avoir lieu à la mi-février 1991.

On attend de connaître les résultats de l'évaluation des propositions du programme Ariane-5 Apex pour pouvoir définir la configuration de lancement et choisir le lanceur qui emportera Cluster. Ceci devrait être confirmé officiellement d'ici début 1991.

ISO

Les premiers équipements de l'Observatoire Spatial à Infrarouge (ISO) vient de subir avec succès une série d'essais parallèles. Le modèle structurel/thermique du module de servitude a été soumis à des essais d'équilibre thermique dans le Grand simulateur spatial (LSS) de l'ESTEC. Le cryostat à hélium liquide du module de charge utile a subi des essais thermiques sous vide chez IABG à Munich, et la



Thermal balance testing of the ISO Service Module structural-thermal model in the Large Space Simulator (LSS) at ESTEC

Tests d'équilibre thermique menés sur le modèle structurel/thermique du module de servitude d'ISO dans le grand simulateur spatial à l'ESTEC accommodating any evolution in the payload's power profile. This configuration has been slightly modified to meet the payload pointing requirements and structural/thermal constraints with sufficient margins.

The Request for Quotation for Phase C/D was issued on 7 September, with proposals from Industry due by 30 November, ready to start Phase C/D on 15 April 1991.

The spacecraft, with a launch mass of 1850 kg now formally agreed with NASA, will be launched by NASA from Kennedy Space Center (KSC) using an Atlas-IIAS. Flight operations will be controlled by NASA from Goddard Space Flight Center (GSFC). Cooperation with NASA is proceeding well and their contributions to the mission are progressing without major problems.

The composition of the industrial team has been carefully constructed, together with the Cluster Project, to achieve an acceptable balance of geographical return, cost and technical performance. All subsystem contractors have been kicked off; units and subsystem proposals are coming in to be incorporated, after formal acceptance by ESA/Matra, in the industrial Phase C/D proposal.

The next major milestone will be the System Design Review in March 1991. In the same time frame, the Science Policy Committee (SPC) and Industrial Policy Committee (IPC) will have to approve the implementation of Phase C/D. This approval will also involve the Cluster project.

The Soho payload is well advanced. Experiment interface definition has progressed considerably and all experiment interface documents were updated prior to the start of Phase-B to provide a clear basis for the system definition and design.

The near-term milestones are the next Science Working Team meeting and submission of the Phase-C/D proposal by Matra, both in the second half of November.

Cluster

During Phase-B2, completed on schedule on 15 September, the industrial consortium was established, culminating in the submission of Phase-C/D proposals from the leading sub-system contractors to the prime contractor.

The overall Phase-C/D proposal from the prime contractor to the Agency was due on 15 October and evaluation is expected to be completed by the end of November, ready for the start of Phase-C/D in February 1991 as planned.

Current activities in Phase-B3 are concentrating on establishment of detailed sub-system design to enable long-delivery parts and materials to be ordered in time. In parallel a number of sub-contracts have been released for advanced Phase C/D activities, which involve the ordering of critical hardware and commencement of sub-system development activities, to maintain the Structural Model schedule; integration is due to start in mid-October 1991.

During Phase-B3 sub-system design reviews are planned with all sub-contractors as a prelude to the submission of the System Design Review package to the Agency in mid-December. Completion of the System Design Review will mark the formal close of Phase-B.

In parallel to Phase-B3 activities, intermediate design reviews are being conducted with all participating experimenter groups in order to freeze the payload design by the System Design Review. The fifth Cluster Science Working Team meeting is planned for the end of November.

The Announcement of Opportunity for the Cluster Science Data System was released as planned and a response is due by the end of December. Interest has been expressed by many institutes outside the Member States and investigations are underway to enable them to participate as a part of the overall distributed system.

The Cluster ground segment design is proceeding as planned with a requirements review scheduled for mid-February 1991.

Results of the evaluation of proposals for the Ariane-5 Apex programme are awaited for definition of the launch configuration and assigned launch vehicle for Cluster. This is expected to be confirmed formally by early 1991.

ISO

The Infrared Space Observatory (ISO) spacecraft has successfully completed an extensive series of parallel tests on the first set of hardware. The service module structural/thermal model has been thermal-balance tested in the ESTEC Large Space Simulator (LSS), the payload module liquid-helium cryostat has been thermal-vacuum tested at IABG, Munich and the telescope was tested for image quality at the Institut d'Astrophysique de Liège (IAL). The test results were all good. A few detailed design improvements only are necessary for the building of the flight-model hardware. The qualification units of the electrical subsystems and flight-model mechanical hardware are being built in parallel.

The first scientific-instrument models have been delivered and are being integrated into a laboratory cryostat for compatibility testing at liquid-helium temperature as a combined scientific payload. The test also affords the opportunity to de-bug test software which will later be used again for satellite system testing and for flight operations.

The scientific-instrument flight models are in manufacture, with a tight schedule demanding delivery in the first quarter of 1991. The German-led Isophot instrument has struck technical problems with its very advanced detector electronics, but very effort is being made to resolve these problems without affecting the schedule.

The observatory ground segment activities are geared to completing the detailed design review at the end of the year. Progress is generally good, although manpower is being stretched with the demand to support parallel testing of hardware and software.

Overall, the project is on schedule for the planned May 1993 launch date.

Huygens

At its meeting of 23 July, the Space Science Working Group (SSWG) endorsed the recommendations of the Huygens Probe Review Committee and these were presented to the Science Programme Committee (SPC) on *qualité de l'image du télescope a été vérifiée à l'Institut d'Astrophysique de Liège (IAL). Tous ces essais ont donné des résultats satisfaisants. Seules quelques améliorations portant sur des détails de conception s'imposent pour la construction du matériel de vol. On fabrique en parallèle les modèles de qualification des sous-systèmes électriques et la partie mécanique du modèle de vol.*

Les premiers modèles des instruments scientifiques ont été livrés et sont en cours d'intégration dans un cryostat de laboratoire, où l'on vérifiera qu'ils sont compatibles entre eux à la température de l'hélium liquide. Ces essais donneront également l'occasion de déterminer le logiciel d'essai qui sera réutilisé ultérieurement pour les essais système du satellite ainsi que pour les opérations en vol.

La fabrication des modèles de vol des instruments scientifiques est en cours et devra respecter un calendrier très serré, la livraison étant prévue pour le printemps 1991. Quant à l'instrument Isophot construit sous maîtrise d'oeuvre allemande, l'électronique extrêmement complexe de son détecteur pose des problèmes techniques qui risquent de remettre en cause le calendrier de réalisation, mais tout est entrepris actuellement pour surmonter ces obstacles.

En ce qui concerne le secteur sol de l'observatoire, on s'efforce d'achever à la fin de cette année la revue de conception détaillée. D'une manière générale, les travaux se poursuivent normalement bien qu'on manque de personnel pour assurer les essais parallèles de matériel et de logiciel.

Dans l'ensemble, le projet respecte le calendrier qui prévoit le lancement en mai 1993.

Huygens

A sa réunion du 23 juillet, le Groupe de travail Science spatiale (SSWG) a approuvé les recommandations du Comité d'examen de la Sonde Huygens qui ont été soumises pour approbation au Comité du Programme scientifique (SPC) les 17 et 18 septembre. La NASA pourrait reporter au-delà de ce qui était prévu à l'origine (première semaine d'octobre 1990) la sélection de la charge utile de Cassini mais l'ESA a conclu avec la NASA un accord aux termes duquel le choix de la charge utile ESA pourra être annoncé dès son approbation par le SPC (voir page 110 pour les dernières nouvelles). La réunion de mise en route qui se tiendra avec les principaux chercheurs de Huygens aura lieu dans le courant de la première quinzaine de novembre.

L'industrie conduit à l'heure actuelle une évaluation des propositions. La procédure d'évaluation devait être entièrement achevée le 10 octobre au plus tard.

ERS

ERS-1

Le modèle de vol a donné toute satisfaction lors des essais vibro-acoustiques réalisés chez Intespace à Toulouse. Il a ensuite été transféré à l'ESTEC où la charge utile a subi, dans le Grand simulateur spatial, des essais d'exposition au soleil et au vide thermique qui mettront un point final au programme d'essais d'ambiance du modèle de vol.

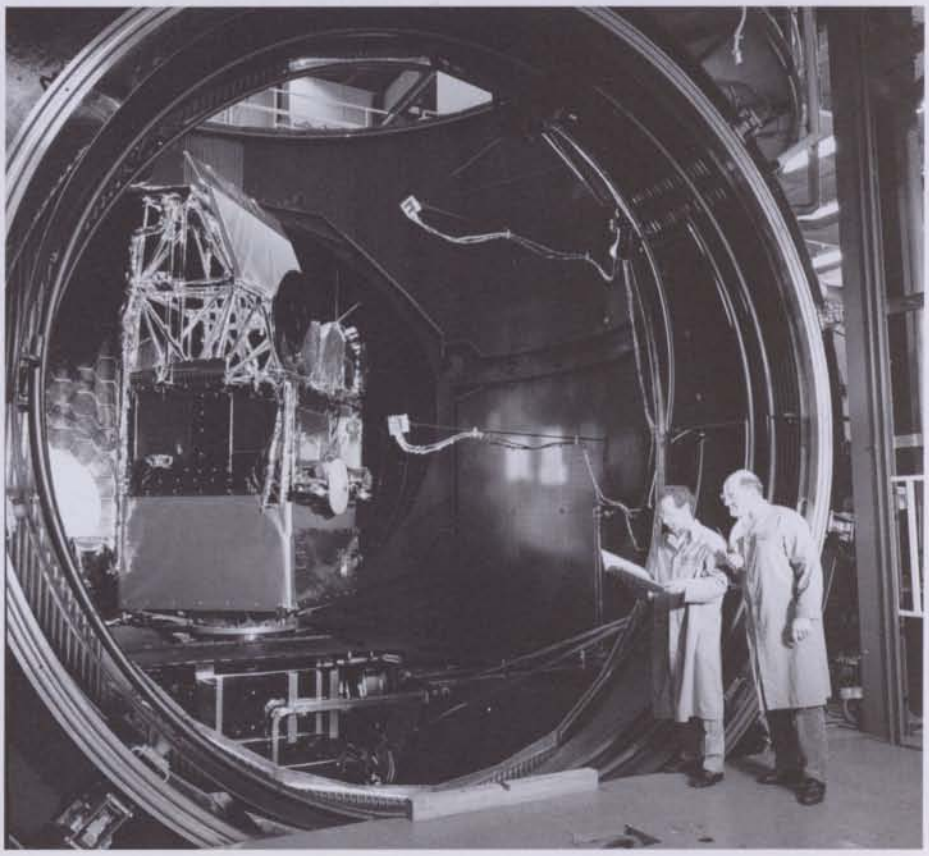
A la suite du remaniement du manifeste d'Ariane, le lancement d'ERS-1 est maintenant prévu en avril 1991.

Lors de sa réunion de juillet, le Conseil directeur du Programme d'Observation de la Terre a approuvé une prolongation de la phase opérationnelle (phase E), principalement afin d'y inclure l'exploitation des quatre installations de traitement et d'archivage (PAF) mises au point, pour une large part, au niveau national.

ERS-2

Le programme ERS-2 a démarré en juillet, dès que le niveau de souscriptions a dépassé les 80% nécessaires.

Les activités industrielles liées non seulement au contrat principal, mais aussi à la fourniture du détecteur hyperfréquences et de l'équipement de mesure précise de la distance et de la vitesse radiale (PRARE) ont été lancées.



ERS-1 payload flight-acceptance tests in the LSS at ESTEC

Test d'aptitude au vol de la charge utile d'ERS-1 dans le LSS à l'ESTEC

17/18 September for approval. NASA selection of the Cassini payload may be delayed later than the first week of October as originally planned but NASA has agreedthat the ESA payload selection can be announced after the SPC approval (see page 110 for latest news). The kick-off meetings with the Huygens Principal Investigators will be held in the first half of November.

The evaluation of proposals from Industry is in progress. The whole evaluation was due for completion by 10 October.

ERS

ERS-1

The flight-model satellite has successfully passed vibration and acoustic noise tests at the Intespace facilities in Toulouse and has since been transported to ESTEC to complete the flight-model environmental test programme, subjecting the payload to thermal vacuum and solar exposure in the Large Space Simulator (LSS) facility.

The ERS-1 launch is now scheduled for April 1991 as a result of the updated Ariane launch manifest.

At its July meeting, the Earth Observation Programme Board approved an expansion of the Operational Phase (Phase-E), mainly to cover operation of the four Processing and Archiving Facilities (PAFs), largely developed nationally.

ERS-2

The ERS-2 Programme started in July when the level of subscription passed 80%.

Industrial work has been initiated not only for the prime contract for the satellite, but also for the procurement of the Microwave Sounder and the Precise Range and Range-rate Equipment (PRARE). Development of the recently approved Global Ozone Monitoring Experiment (GOME) has started.

Contract negotiations, including possible redistribution of work for reasons of geographical distribution, are due to be completed by the end of the year.

EOPP

Aristoteles

The Aristoteles Additional Study Baseline Design Review (BDR) was successfully completed, and on 20 July final agreement on the project specifications and plans was reached.

Work has progressed at CISET (I) on the improvement of the gradiometric performance simulation software.

An Aristoteles 'Dedicated Launch System Study' was kicked off at ESTEC on 19 July, in order to assess the implications of a dedicated launch by Delta II in the framework of the envisaged NASA/ESA cooperation.

A contract for development of the breadboard model of the Gradio calibration mechanism has started with TPD (NL).

On the scientific users' side, the mid-term presentation of the University of Bologna's study on the geophysics impact of Aristoteles took place at ESTEC in May.

Discussions have also been held with NASA on a cooperative ESA/NASA mission as an alternative to the mission envisaged so far.

Meteosat Second Generation (MSG)

The studies of missions and of three-axis stabilised satellites performed by industrial teams led by Aerospatiale and British Aerospace were completed at the end of May with a presentation to ESA and Eumetsat.

Studies by TPD (NL) on a High-Resolution Visible Imager and by Aerospatiale on a High-Spectral-Resolution Sounder have been successfully completed.

A mid-term review on data dissemination technology took place in ESTEC in June. Invitations-to-Tender have been sent to Industry for a study to investigate the many new and alternative types of antenna, which could could have a major impact at satellite level.

Polar-Orbit Missions

Following completion of Phase-A activities for the First Polar Mission (FPM), a presentation was made to Delegations at ESTEC, 3–5 July.

Coordination with the Polar Platform Programme has been pursued not only at technical level, but also at programmatic level, to harmonise the contents of the Polar Platform and Polar-Orbit Earth-Observation Mission (POEM) Programmes.

Further assessment of the Announcement-of-Opportunity instruments for POEM-1 was carried out in preparation for joint consideration in September by the Earth Observation Programme Board and the Science Programme Committee.

Two coordination meetings with NASA have been held in ESTEC for the implementation of the Multifrequency Imaging Microwave Radiometer (MIMR) on the first NASA Polar Platform.

Meteosat

Meteosat-4 (MOP-1) continues to be used as the operational spacecraft, with Meteosat-3 (P2) as in-orbit stand-by. The investigation into the MOP-1 anomalies has been completed. The cause of the 'fish' image anomaly is now fully understood and corrections are being introduced in the later spacecraft.

The launch of MOP-2 is now scheduled for February 1991 with the launch campaign starting just after the New Year.

Eumetsat has requested a proposal from the Agency for one more MOP-type spacecraft with an option for a second flight unit. In support of this, Eumetsat requested and authorised ESA to procure components for one flight unit.

Earthnet

The data flow from Landsat MSS and TM, NOAA AVHRR and MOS MESSR, MSR and VTIR missions have been regularly acquired, processed and disseminated by the Earthnet ground stations.

The fully operational status of the Earthnet Tiros AVHRR coordinated network has led to an increase in the number of users interested in this type of data. The central catalogue in Frascati holds the data acquired at the

La mise au point de l'expérience de surveillance de l'ozone à l'échelle du globe (GOME) a également été engagée.

Les négociations contractuelles, y compris les modifications ayant trait à la redistribution éventuelle des travaux pour des raisons d'équilibre géographique, devraient être achevées d'ici la fin de l'année.

EOPP

Aristoteles
La revue du concept de référence faisant suite à l'étude complémentaire sur Aristoteles s'est déroulée de manière satisfaisante et un accord final a été conclu le 20 juillet sur les plans et spécifications du projet.

Les travaux visant à améliorer le logiciel de simulation des performances du gradiomètre suivent leur cours à la CISET (I).

Une étude sur le système de lancement spécifique d'Aristoteles a été lancée à l'ESTEC le 19 juillet afin d'analyser les implications d'un lancement spécifique par Delta II dans le cadre de la coopération envisagée avec la NASA.

Un contrat de mise au point du montage table du mécanisme d'étalonnage du Gradio a été signé avec TPD (NL).

En ce qui concerne les utilisateurs scientifiques, une présentation à mi-parcours de l'étude de l'Université de Bologne sur la contribution de la mission Aristoteles dans le domaine de la géophysique a eu lieu à l'ESTEC en mai dernier.

Des négociations se sont également déroulées avec la NASA au sujet d'une mission commune ESA/NASA qui pourrait remplacer la mission envisagée jusqu'ici.

Mètèosat de deuxième génération (MSG)
Les études de missions et de satellites à stabilisation triaxiale entreprises sous la conduite d'Aérospatiale et de British Aerospace se sont terminées fin mai par une présentation devant l'ESA et Eumetsat.

L'étude de TPD sur l'instrument imageur à haute résolution dans le visible et celle d'Aérospatiale sur le détecteur à haute résolution spectrale ont été menées à bien.

Une revue à mi-parcours sur la technique de diffusion des données a eu lieu à l'ESTEC en juin. Un appel d'offres portant sur l'étude des nouveaux types d'antenne susceptibles d'avoir une incidence notable sur le satellite a été adressé à l'industrie.

Missions sur orbite polaire
Les activités de phase A de la première mission polaire (FPM) ont été suivies d'une présentation aux délégations du 3 au 5 juillet à l'ESTEC.

La coordination avec le Programme Plate-forme polaire se poursuit aux niveaux technique et programmatique. Elle a pour objet d'harmoniser les programmes Plate-forme polaire et Mission d'Observation de la Terre sur Orbite polaire (POEM).

L'évaluation de l'offre de participation relative aux instruments de POEM-1 s'est poursuivie en vue d'un examen commun en septembre par le Conseil directeur du Programme d'Observation de la Terre et par le Comité du Programme scientifique.

Deux réunions de coordination avec la NASA ayant pour objet de mettre en oeuvre le radiomètre imageur hyperfréquences multifréquences (MIMR) sur la première plate-forme polaire de la NASA se sont tenues à l'ESTEC.

Météosat

Météosat-4 (MOP-1) continue de fonctionner comme satellite opérationnel, tandis que Météosat-3 (P-2) fait office de satellite de réserve en orbite. L'analyse des anomalies de MOP-1 a été menée à bien. L'origine de l'anomalie d'image (rayures de type 'poissons') ayant été décelée, on procède actuellement à des modifications sur le satellite.

Le lancement de MOP-2 est maintenant prévu en février 1991. La campagne de lancement commencera juste après le Nouvel An.

Eumetsat a demandé à l'Agence de formuler une proposition portant sur un satellite supplémentaire du type MOP, avec option pour une deuxième unité de vol. A cet effet, Eumetsat a demandé officiellement à l'ESA de procéder à l'approvisionnement de composants pour une unité de vol.

Earthnet

Les stations sol du réseau Earthnet assurent régulièrement l'acquisition, le traitement et la diffusion des données MSS et TM de Landsat, AVHRR de la NOAA, MESSR, MSR et VTIR du MOS.

Le réseau coordonné Earthnet pour la transmission des données AVHRR de Tiros est maintenant parfaitement opérationnel, ce qui a entraîné une augmentation du nombre des utilisateurs désireux de mettre à profit ce type de données pour leurs travaux. Les données acquises par les stations sol de Maspalomas, Tromsø, Dundee, Oberpfaffenhofen, Rome-ITAV et Niamey sont stockées dans la base de données du catalogue central de Frascati. Les services mis à la disposition des utilisateurs peuvent fournir par télécopie des images à 'consultation rapide' et distribuent des données sous forme numérique corrigées des erreurs de système.

L'ESA et la CEE (DG VIII) ont approuvé l'extension de l'accord relatif à l'utilisation de la station de Maspalomas pour l'acquisition jusqu'à fin 1991 de données de Spot, de Tiros et de Landsat au-dessus de l'Afrique occidentale.

L'acquisition et le prétraitement des données de Spot à Maspalomas se déroulent conformément aux prévisions. Les essais d'acquisition réalisés avec Spot-2 dans la perspective de la mise hors service anticipée de Spot-1 ont donné toute satisfaction.

ERS-1
La prolongation de la phase opérationnelle d'ERS-1 ayant été récemment approuvée, des contrats ont été lancés qui doivent permettre l'exploitation, à partir de 1991, des quatre installations de traitement et d'archivage d'ERS-1, à la maintenance du logiciel et à l'exploitation de l'installation centrale d'Earthnet, ainsi qu'aux travaux de mise à niveau des

Maspalomas, Tromsø, Dundee, Oberpfaffenhofen, Rome-ITAV and Niamey ground stations. The relevant quick-look imagery is available via telefax through the user service, which also distributes system-corrected data in digital form.

ESA has signed with the EEC (DG VIII) the extension of the agreement for the utilisation of the Maspalomas Station to acquire Spot, Tiros and Landsat data over West Africa until end of 1991.

Spot data recording and pre-processing continues to be performed nominally at Maspalomas. Acquisition tests with Spot-2 have been successfully performed in anticipation of the retirement of Spot-1.

ERS-1

With the recent approval of the enlargement of the ERS-1 operational phase, contracts have been initiated for the operation, in the period 1991 onwards, of the four ERS-1 Processing and Archiving Facilities, for the software maintenance and operations of the Earthnet Central Facility and for the upgrading of the Maspalomas (ERS-1 SAR) and Prince Albert (ERS-1 LBR) stations.

The capability of ERS-1 to provide data relevant to environmental problems was demonstrated by Earthnet at the EARSeL Annual Conference in Toulouse, as well as at the '1990 Oceans from Space' Conference in Venice and at the 'International Water Resources Symposium' in Enschede.

Eureca

With the delivery of the attitude-and-orbital-control subsystem by the end of May the integration of Eureca and its 15 flight instruments was completed by mid-June.

First compatibility tests between the Eureca integrated flight unit located at MBB/ERNO in Bremen (D) and the European Space Operations Centre (ESOC) in Darmstadt (D) have proved that the telemetry data can be processed by ESOC and that Eureca can be remotely commanded and operated from Darmstadt.

With a visit of the NASA crew to the Eureca integration site, the technical discussions to clarify the Eureca interfaces with the NASA Shuttle System are almost complete.

ESA astronaut Claude Nicollier has been assigned the responsibility of performing the Eureca deployment operations with the manipulator arm of the Shuttle Discovery during the first day in orbit.

The integrated Eureca flight system is now undergoing its final system-qualification and acceptance tests, which are scheduled to be completed by November.

NASA has rescheduled the launch of Eureca for the end of 1991 or January 1992, with retrieval scheduled for mid-1992.

Space Station Freedom/Columbus

Polar Platform

Further detailed definition of the Polar Platform has continued in order to correct some of the initial proposal deficiencies and to refine requirements in the area of payload capabilities.

Requirements and design have been revised in the area of data management, communication and thermal control to ensure a better match with future missions and payloads. The development/test approach has also been reviewed to ensure a more efficient symbiosis with the payload development. Following the formal re-issue of ESA management and technical requirements, the Polar Platform industrial consortium is preparing an update to the existing proposal.

TDP

Experiments

The Gallium Arsenide Solar Array (GaAs) second phase, involving 2 × 4 cm cells with welded interconnectors, has completed component testing.

The Solid-State Micro-Accelerometer flight unit was scheduled to be shipped to the launch site in September. Manufacture of the Attitude Sensor Package flight unit has begun. An end-to-end test to check experiment compatibility with the Space Shuttle is being carried out this Autumn.

A critical test in the Collapsible Tube Mast (CTM) bridging phase is scheduled for the latter part of this year. Preparatory activities for the development phase have begun.

The Liquid-Gauging Technology Critical Design Review has been shifted to October/November.

Photo: MBB/ERNO

L'équipage de la navette Discovery en visite sur le site d'intégration d'Eureca à MBB/ERNO

The Discovery crew visit the Eureca integration site at MBB/ERNO *stations de Maspalomas (SAR d'ERS-1) et de Prince Albert (LBR d'ERS-1).*

A l'occasion de la conférence annuelle de l'EARSeL à Toulouse, de la conférence sur les océans vus de l'Espace qui s'est tenue à Venise en 1990 et du symposium international sur les ressources en eau d'Enschede, Earthnet a demontré que les données d'ERS-1 étaient adaptées à l'étude des problèmes d'environnement.

Eureca

Le sous-système de commande d'orientation et de correction d'orbite ayant été livré fin mai, l'intégration d'Eureca et de ses 15 instruments de vol était achevée à la mi-juin.

Les premiers essais de compatibilité entre le Centre européen d'opérations spatiales de Darmstadt (D) et l'unité de vol intégrée d'Eureca se trouvant chez MBB/ERNO à Brême (D) ont démontré que l'ESOC peut traiter les données de télémesure d'Eureca et que celui-ci peut être télécommandé et exploité à partir de Darmstadt.

Grâce à une visite de l'équipage NASA qui accompagnera Eureca à bord de la Navette, les discussions techniques destinées à éclaircir les questions d'interfaces entre Eureca et le système de la Navette américaine sont presque à leur terme.

C'est l'astronaute ESA Claude Nicollier qui assumera la responsabilité des opérations d'extraction d'Eureca de la soute de la Navette Discovery au moyen du bras télémanipulateur le jour de la mise en orbite.

On conduit actuellement sur le modèle de vol intégré d'Eureca les derniers essais de qualification et de recette au niveau système; ils doivent prendre fin d'ici le mois de novembre.

La NASA a reprogrammé le lancement d'Eureca pour fin 1991 ou janvier 1992. Sa récupération est fixée à la mi-1992.

Station Spatiale Freedom/Columbus

Plate-forme polaire

La définition détaillée de la plate-forme polaire se poursuit en vue de remédier à certaines lacunes de la proposition initiale et de mieux préciser les exigences en matière de charges utiles.

Les impératifs et la conception de la gestion des données, des télécommunications et de la régulation thermique ont été révisés dans l'optique d'une meilleure adaptation aux charges utiles et aux missions futures. Les procédures de mise au point et d'essai ont également été réexaminées en vue d'une meilleure harmonisation avec la réalisation de la charge utile. Compte tenu du remaniement des impératifs techniques et des exigences de gestion de l'ESA, le consortium industriel chargé de la plate-forme polaire s'emploie actuellement à mettre à jour la proposition existante.

TDP

Expériences

Réseau solaire à l'arséniure de Gallium (GaAs): les essais des composants destinés à la deuxième phase de cette expérience qui porte sur des piles de 2×4 cm à interconnecteurs soudés sont maintenant terminés.

Micro-accéléromètre à l'état solide: l'unité de vol doit être expédiée sur le site de lancement en septembre.

Ensemble de détecteurs d'orientation: la fabrication de l'unité de vol a conmencé. Un essai de bout en bout sera conduit cet automne afin de vérifier la compatibilité de l'expérience avec la Navette spatiale.

Mât à tube enroulable (CTM): pour la phase relais, un essai critique est prévu à la fin de l'année. Les activités de préparation de la phase de réalisation ont commencé.

Technologie de jaugeage des liquides: la revue de conception critique a été reportée à octobre/novembre.

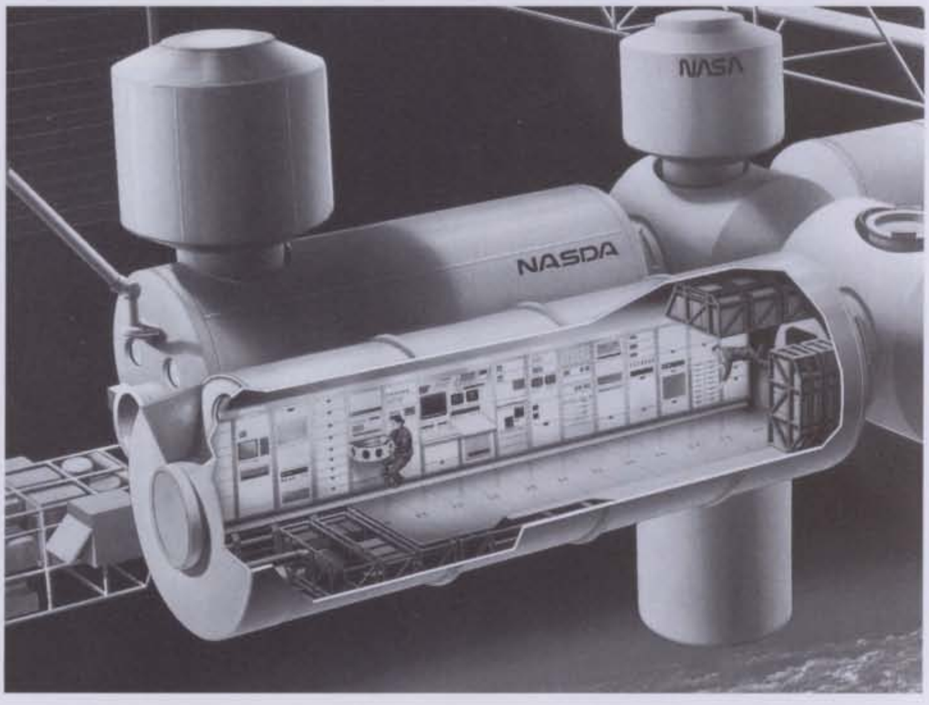
Technologie de structures gonflables, rigidifiables dans l'espace: la phase B de cette expérience a commencé en septembre.

Ecoulement diphasique: la revue de conception préliminaire est fixée à septembre/octobre.

Détecteur d'oxygène atomique: les activités portant sur cette nouvelle expérience ont été engagées en août.

Expériences en coopération ESA/NASA

En ce qui concerne l'expérience de contamination en vol (IFCE), le Groupe de travail ESA/NASA constitué pour définir un système simple de largage du mât à tube enroulable (CTM) respectant les impératifs de sécurité a mené sa



Artist's impression of Columbus

Vue d'artiste de Columbus

Phase-B of the Inflatable Space-Rigidised Technology Experiment started in September while the Two-Phase Flow Experiment Preliminary Design Review is scheduled for September/October.

A new experiment, the Atomic Oxygen Detector, was initiated in August.

ESA/NASA cooperative experiments
With regard to the In-Flight Contamination Experiment (IFCE), the ESA/NASA Working Group established to define a simple Collapsible Tube Mast (CTM) jettison system compliant with safety requirements has successfully completed its task. The decision to proceed with Phase-C/D is pending the CTM critical test results.

Flight opportunities
Launch of the Solid State Microaccelerometer, a Shuttle Get-Away Special (G-21) on-board STS-40, has been delayed, probably until January 1991. The Hitchhiker-G experiment (Attitude Sensor Package) launch has been set for January 1992, on STS-50. The STRV-1 launch, carrying the Gallium Arsenide Solar Array Panel, is scheduled for early 1992, while the Bremsat launch carrying the Atomic Oxygen Detector is scheduled for mid-1992.

TDP Next-Phase Preparation
The first meeting of the Potential Participants was held in September.

Ariane

Ariane-5
The Ariane-5 Development Programme is proceeding according to plan. Major definitions have been frozen and the first real hardware tests have started. Results are encouraging and give confidence in the future of the Programme. Preliminary design reviews have been completed and overall definitions have been confirmed.

Testing of the main cryotechnic engine Vulcain is progressing satisfactorily and on schedule; the first low-pressure engine ignition sequence was held on 31 August.

Similarly, the first full-scale flexible nozzle of the P230 solid boosters is undergoing a series of gimbal tests.

Nearly 100 tests have been carried out on the second stage L7 combustion chamber at the Lampoldshausen test site, covering the whole range of conditions foreseen for this engine.

An important milestone of the programme will be reached shortly when the Vulcain engine is submitted to a complete ignition and combustion sequence test.

Hermes

Technical aspects
Following the decisions on the main options for the spaceplane, Industry has updated the proposed spaceplane configuration including the accommodation of subsystems and critical functions. This configuration has also taken into account the requirements for access for integration and maintenance.

In addition to optimising the spaceplane layout, another aim was to move the centre-of-gravity further forward to balance the spaceplane for atmospheric re-entry. An improved aerodynamic shape has been obtained with intensive computational fluid dynamic studies.

The combination of the new layout and the new aerodynamic shape provide the Hermes Stage-1 configuration, which will be the reference for the Development Phase industrial proposal.

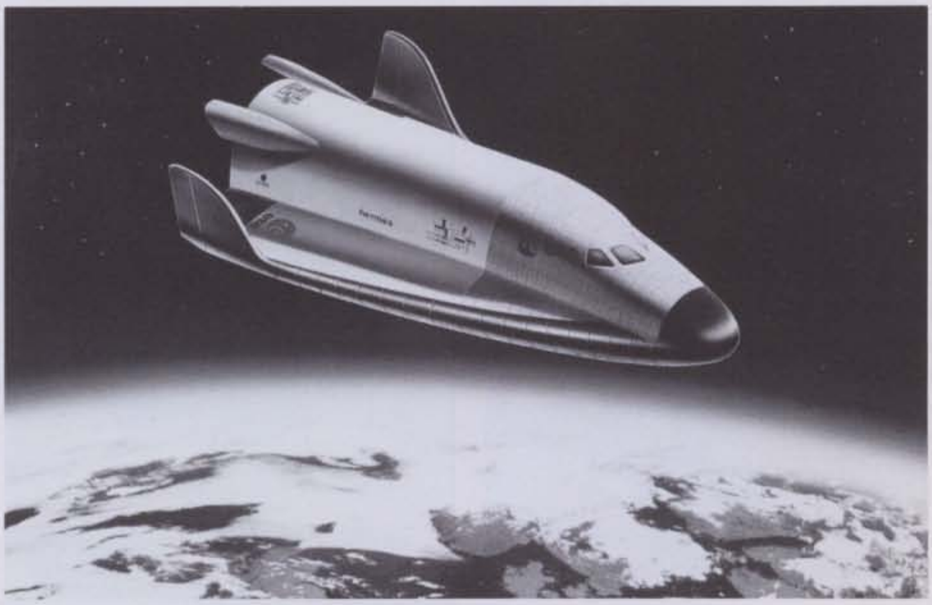
Tests on critical extra-vehicular activity (EVA) components are progressing. The programme review for the Hermes Robotic Arm (HERA) and EVA has started with Industry.

Ground-segment definition is progressing with the functional definition of each element and the definition of the possible architecture of the system. Emphasis has been placed on the flight control centre definition and the trade-offs for various operational facilities.

The Development Phase Request for Proposals has been issued. Preparation of the programmatic file as support to the Hermes Phase-2 decision is well underway. In view of the delay into 1991 of this decision, a proposal for a transition budget has been submitted.

Management aspects
The definition, together with CNES, of the setting up and operation of a common ESA/CNES programme team has been completed and the team has been in operation since 1 August.

Industry has prepared plans to improve the system management of the spaceplane. One major step in this process is the direct participation of Dassault, Aeritalia and DASA in this management. This new organisation and other improvements in the industrial structure will be announced by the end of the Autumn.



Vue d'artiste de l'avion spatial Hermès

Artist's impression of the Hermes spaceplane *tâche à bonne fin. On attend les résultats des essais du CTM pour engager la phase C/D.*

Occasions de vol

Le lancement du micro-accéléromètre à l'état solide en conteneur GAS (GAS-21) sur le STS-40 a été reporté, probablement jusqu'à janvier 1991. Le lancement de l'expérience Hitchhiker-G (ensemble de détecteurs d'orientation) a été fixé à janvier 1992, lors du vol STS-50. Le lancement de STRV-1, qui emportera l'expérience de réseau solaire à l'arséniure de gallium, est fixé au début 1992 et celui de Bremsat, avec le détecteur d'oxygène atomique, à la mi-1992 .

Préparation de la phase suivante du TDP

La première réunion des Participants potentiels se tiendra en septembre.

Ariane

Ariane-5

Le programme de développement Ariane-5 se déroule conformément au calendrier. Les principales définitions ont été figées et la première série d'essais de matériels en conditions réelles a commencé. Les résultats encourageants qui ont été obtenus incitent à avoir confiance en l'avenir du programme. Toutes les revues de conception préliminaires sont achevées et les définitions globales confirmées.

Les essais du moteur cryotechnique Vulcain se déroulent de manière satisfaisante et conformément au calendrier. Le premier essai d'allumage moteur à basse pression a eu lieu le 31 août.

De même, la butée flexible en grandeur réelle des propulseurs à poudre P230 subit actuellement une première série d'essais de torsion.

La chambre de combustion du deuxième étage L7 a subi au centre de Lampoldshausen une centaine d'essais englobant l'ensemble des conditions d'expérimentation prévues pour ce moteur.

Une étape importante sera franchie sous peu, lorsque le moteur Vulcain sera soumis à un essai complet de séquence allumage-combustion.

Hermès

Aspects techniques

Compte tenu des décisions prises au sujet des principales options de l'avion spatial, l'industrie a révisé la proposition de configuration d'Hermès, y compris l'emplacement des sous-systèmes et des fonctions critiques. Cette nouvelle configuration prévoit également les impératifs d'accès pour l'intégration et la maintenance.

Outre l'amélioration de l'agencement, il a été décidé de déplacer vers l'avant le centre de gravité de l'avion afin d'assurer son équilibre lors de sa rentrée dans l'atmosphère. La forme aérodynamique du véhicule a pu être améliorée grâce à des études de simulation intensives de dynamique des fluides.

Ces nouvelles définitions de l'agencement et de la forme aérodynamique de l'avion spatial constituent la configuration de phase 1, qui servira de référence aux propositions industrielles de phase de développement.

Les essais portant sur les éléments critiques servant aux activités extra-véhiculaires (EVA) sont en bonne voie.

La revue de programme relative aux activités EVA et au bras télémanipulateur d'Hermès (HERA) a démarré avec l'industrie.

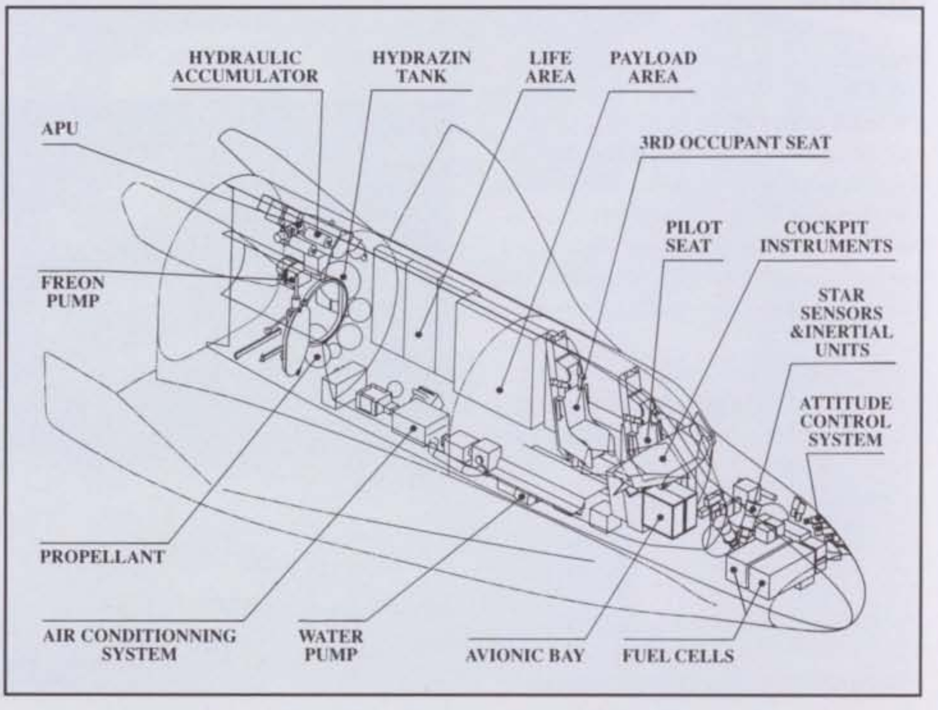
Pour ce qui concerne le secteur sol, la définition des fonctions de chaque élément et de l'architecture éventuelle du système est en cours. L'accent a été mis sur la définition du Centre de contrôle des opérations en vol et sur les arbitrages en matière de moyens opérationnels.

La demande de proposition pour la phase de développement de l'avion spatial a été lancée. La préparation du dossier programmatique sur lequel s'appuiera la décision de passage à la phase 2 est en bonne voie. Cette décision étant reportée à 1991, un budget de transition a été proposé.

Gestion

La composition et le fonctionnement d'une équipe intégrée ESA/CNES ont été définis avec le CNES. Cette équipe est opérationnelle depuis le 1er août.

L'industrie a élaboré des projets visant à améliorer la gestion d'Hermès au niveau système. Un pas important a été franchi à cet égard avec la participation directe de Dassault, d'Aeritalia et de la DASA à ladite gestion. Cette nouvelle organisation ainsi que d'autres améliorations de la structure industrielle seront rendues publiques d'ici à la fin de l'automne.



Latest configuration of the Hermes spaceplane

Configuration la plus récente de l'avion spatial Hermès

Publications

The documents listed have been issued since the last publications announcement in the Bulletin. Requests for copies should be made in accordance with the Table and using the Order Form inside the back cover of this issue.

ESA Journal

The following papers have been published in ESA Journal Vol. 14, No. 3:

A SEARCH FOR NEW STORABLE HIGH-PERFORMANCE PROPELLANTS
MUL J M ET AL

THE LIQUID-DROP RADIATOR – AN ADVANCED FUTURE HEAT-REJECTION SYSTEM
PERSSON J

THE GPS INTEGRATED NAVIGATION AND ATTITUDE-DETERMINATION SYSTEM (GINAS)
LUCAS R & MARTIN-NEIRA M

ATTITUDE DYNAMICS OF THE TETHER ELEVATOR/CRAWLER SYSTEM FOR MICROGRAVITY APPLICATIONS
VETRELLA S ET AL

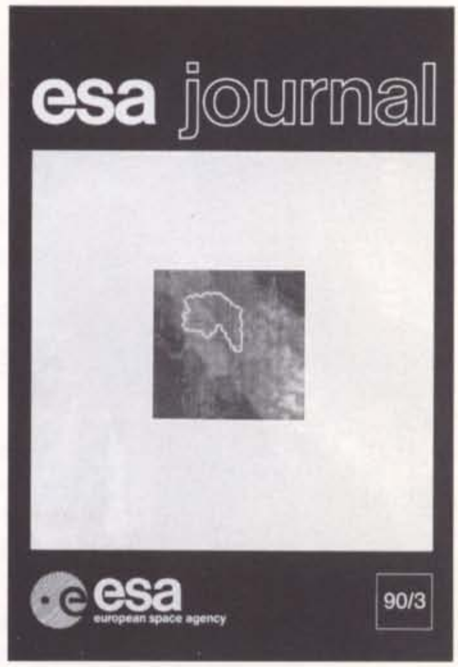
OPERATIONAL RAINFALL ESTIMATION USING METEOSAT INFRARED IMAGERY: AN APPLICATION IN ITALY'S ARNO RIVER BASIN
LEVIZZANI V ET AL

USER INTERFACES FOR INFORMATION SYSTEMS
BELKIN N J ET AL

ESA Special Publications

ESA SP-303 // 461 PAGES
SPACE APPLICATIONS OF ADVANCED STRUCTURAL MATERIALS, PROC ESA SYMPOSIUM, ESTEC, NOORDWIJK, THE NETHERLANDS, 21–23 MARCH 1990 (JUNE 1990)
BURKE W R (ED)

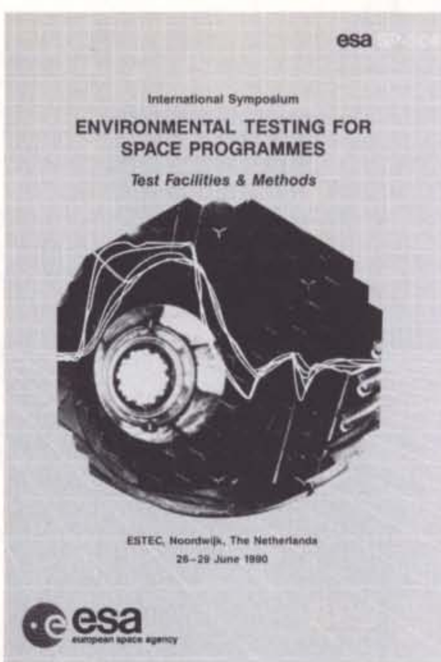
ESA SP-304 // 576 PAGES
ENVIRONMENTAL TESTING FOR SPACE PROGRAMMES – TEST FACILITIES & METHODS, PROC INTERNATIONAL SYMPOSIUM, ESTEC, NOORDWIJK, THE NETHERLANDS, 26–29 JUNE 1990 (SEPTEMBER 1990)
GUYENNE T D & HUNT J J (EDS)

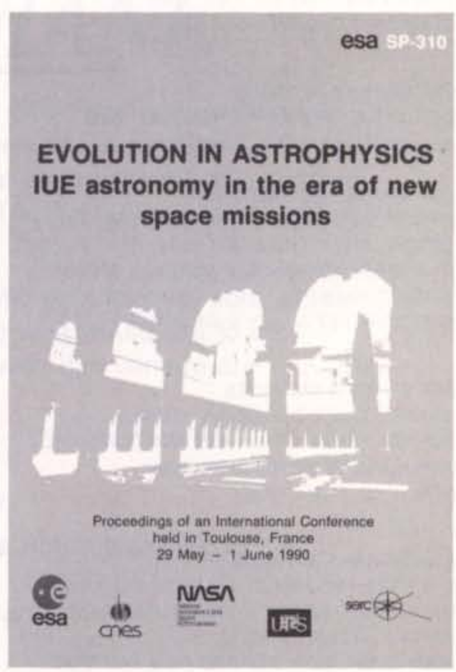


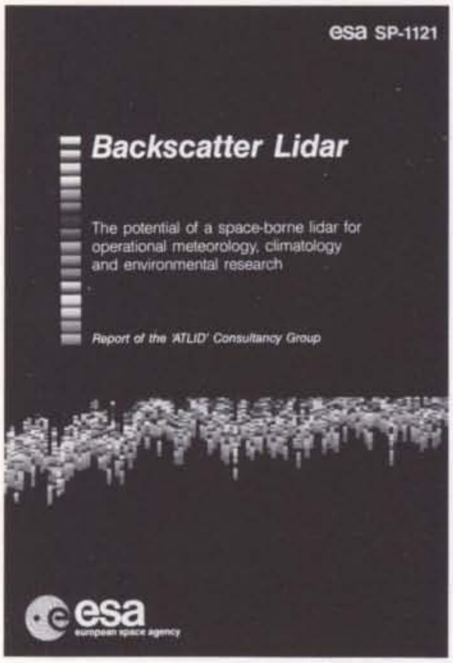
ESA SP-307 // 660 PAGES
PROC FOURTH EUROPEAN SYMPOSIUM ON LIFE SCIENCES RESEARCH IN SPACE, TRIESTE, ITALY, 28 MAY – 1 JUNE 1990 (NOVEMBER 1990)
DAVID V (ED)

ESA SP-310 // 643 PAGES
EVOLUTION IN ASTROPHYSICS: IUE ASTRONOMY IN THE ERA OF NEW SPACE MISSIONS, PROC INTERNATIONAL CONFERENCE, TOULOUSE, FRANCE, 29 MAY – 1 JUNE 1990 (AUGUST 1990)
ROLFE E J (ED)

ESA SP-311 // 353 PAGES
PLASMA ASTROPHYSICS, PROC JOINT WORKSHOP, TELAVI, GEORGIA, USSR, 4–12 JUNE 1990 (AUGUST 1990)
GUYENNE T D & HUNT J J (EDS)







ESA SP-315 // 225 PAGES
FORMATION OF STARS AND PLANETS, AND THE EVOLUTION OF THE SOLAR SYSTEM, PROC 24TH ESLAB SYMPOSIUM, 17-19 SEPTEMBER 1990 (NOVEMBER 1990)
BATTRICK B (ED)

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HORIZONTES MAS AMPLIOS (WIDER HORIZONS: SPANISH EDITION) (NOVEMBER 1990)
HOOD V & LONGDON N (EDS)

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THE SOLAR-TERRESTRIAL SCIENCE PROJECT OF THE INTER-AGENCY CONSULTATIVE GROUP FOR SPACE SCIENCE (IACG) – KEY DATA ON PARTICIPATING PROJECTS (NOVEMBER 1990)
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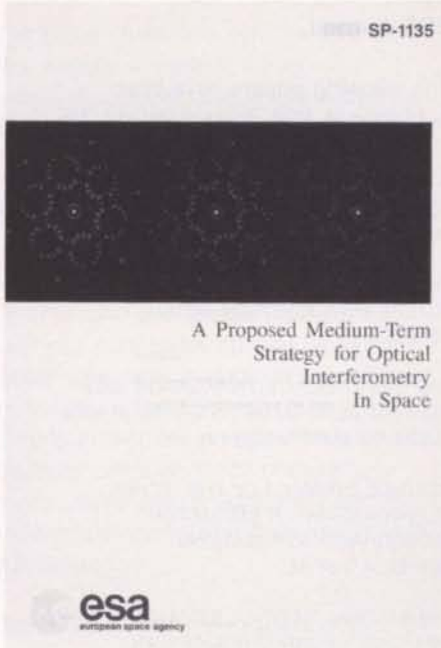
MIMR PANEL (EDS: C BARRON & B BATTRICK)



ESA Brochures

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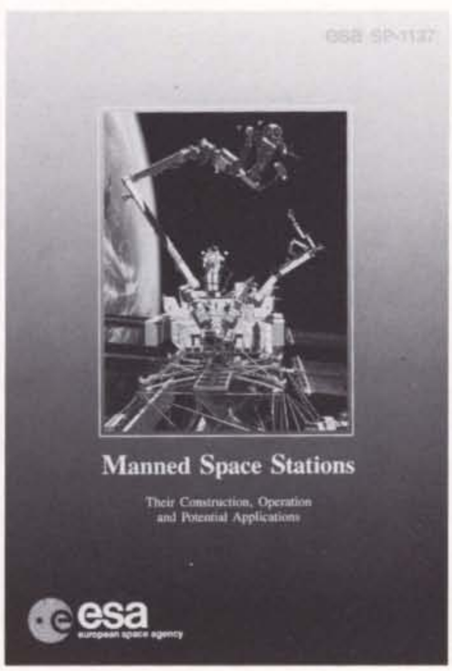
AN OLD LEGEND, NEW SCIENCE – ULYSSES (JULY 1990)
MARSDEN R G (ED: N LONGDON)

ESA Newssheets

EARTH OBSERVATION QUARTERLY // 8 PAGES
NO. 31 (SEPTEMBER 1990)
GUYENNE T D (ED)

MICROGRAVITY NEWS FROM ESA // 4 PAGES
SPECIAL ISSUE – FLIGHT OPPORTUNITIES (OCTOBER 1990)
LONGDON N (ED)

MICROGRAVITY NEWS FROM ESA // 24 PAGES
VOL 3, NO 2 (NOVEMBER 1990)
DAVID V (ED)



NEWS & VIEWS // 8 PAGES
ESA-IRS NEWSLETTER, VOL 15 NO 3 (SEPTEMBER 1990)
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ESA Scientific & Technical Memoranda

ESA STM-243 // 66 PAGES
FEASIBILITY OF IN-ORBIT TESTING OF INFLATABLE ANTENNAS WITH CELESTIAL SOURCES (JUNE 1990)
BAARS J W M (ED: W R BURKE)

Procedures, Standards and Specifications

ESA PSS-03-105 ISSUE 1
ESATAN USER MANUAL (APRIL 1990)
THERMAL CONTROL & LIFE SUPPORT DIVISION, ESTEC

ESA PSS-06-101 ISSUE 1
ECOS USER'S MANUAL AND MENU NAVIGATOR (JANUARY 1990)
COST ANALYSIS DIVISION, ESTEC

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C 3 - Professur Raumtransporttechnologie

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