esa bulletin

number 50

may 1987

european space agency

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

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

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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. Finlande est membre associé de l'Agence. Le Canada beneficie d'un statut d'Etat coopérant.

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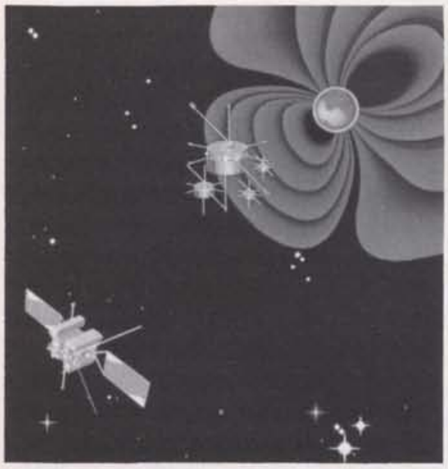

Front cover: Artist's impression of the Soho and Cluster mission spacecraft (see page 8).

Back cover: Latest Giotto HMC image of the Comet Halley nucleus, processed by DFVLR, courtesy of H.U. Keller
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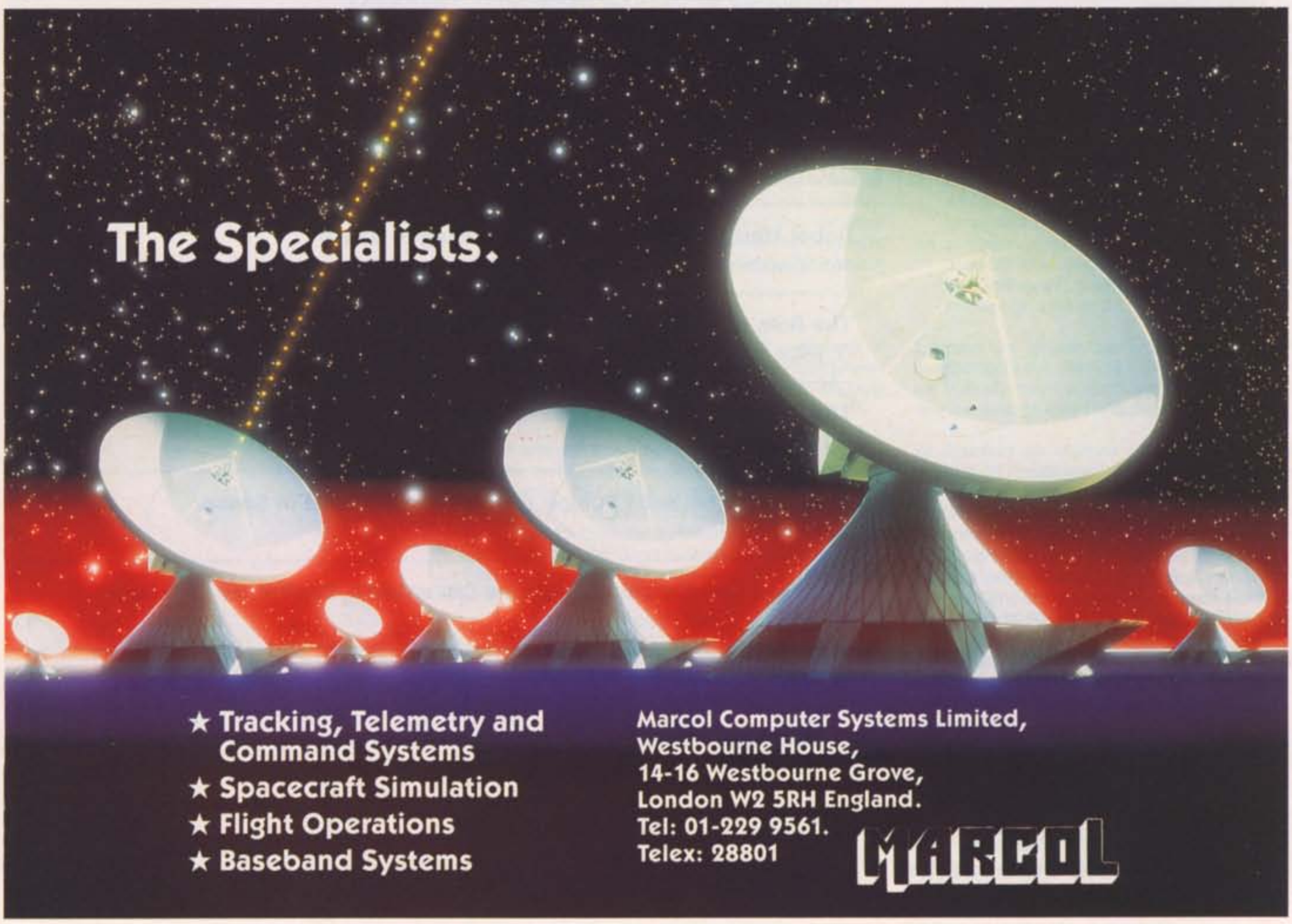
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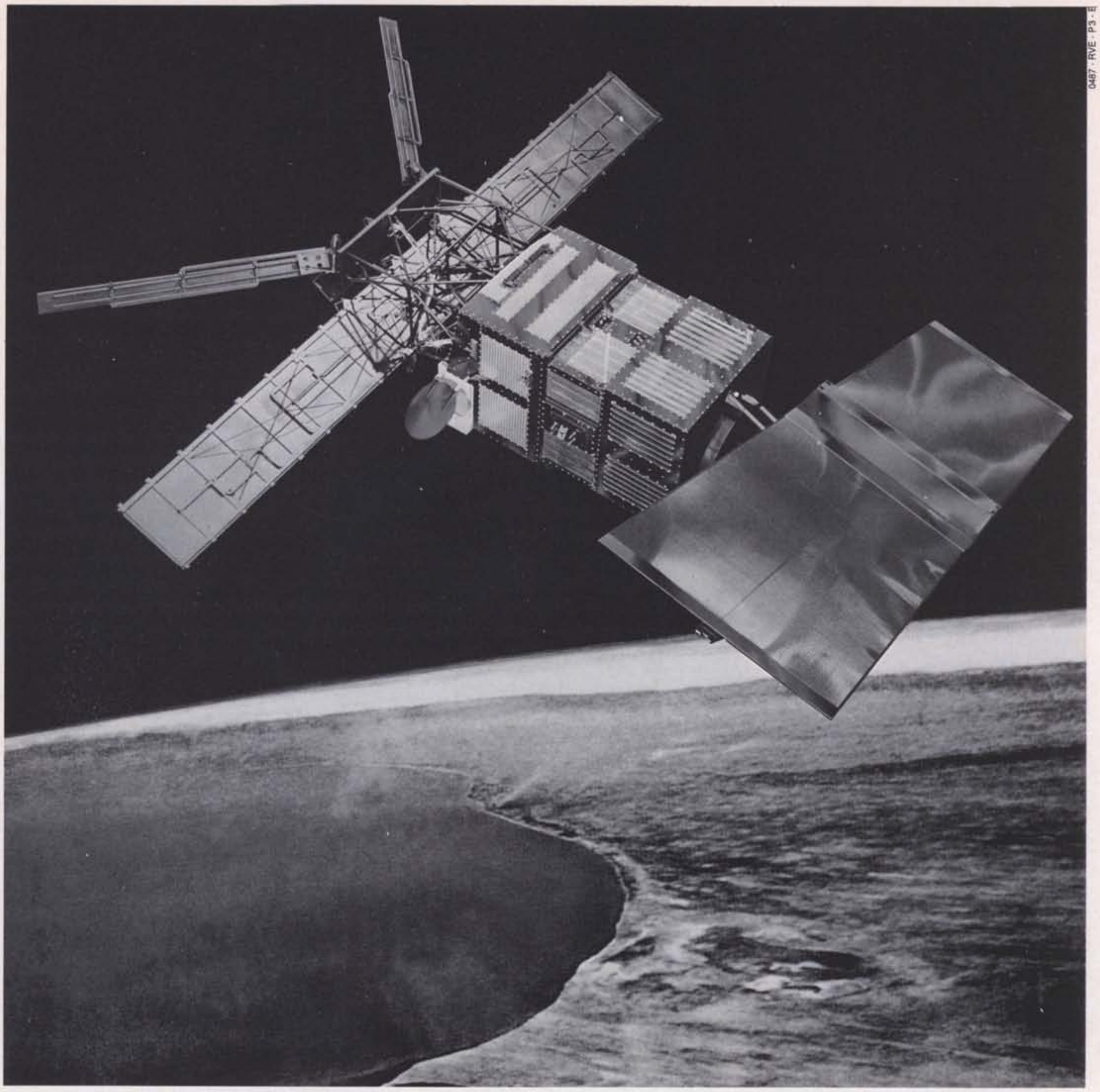

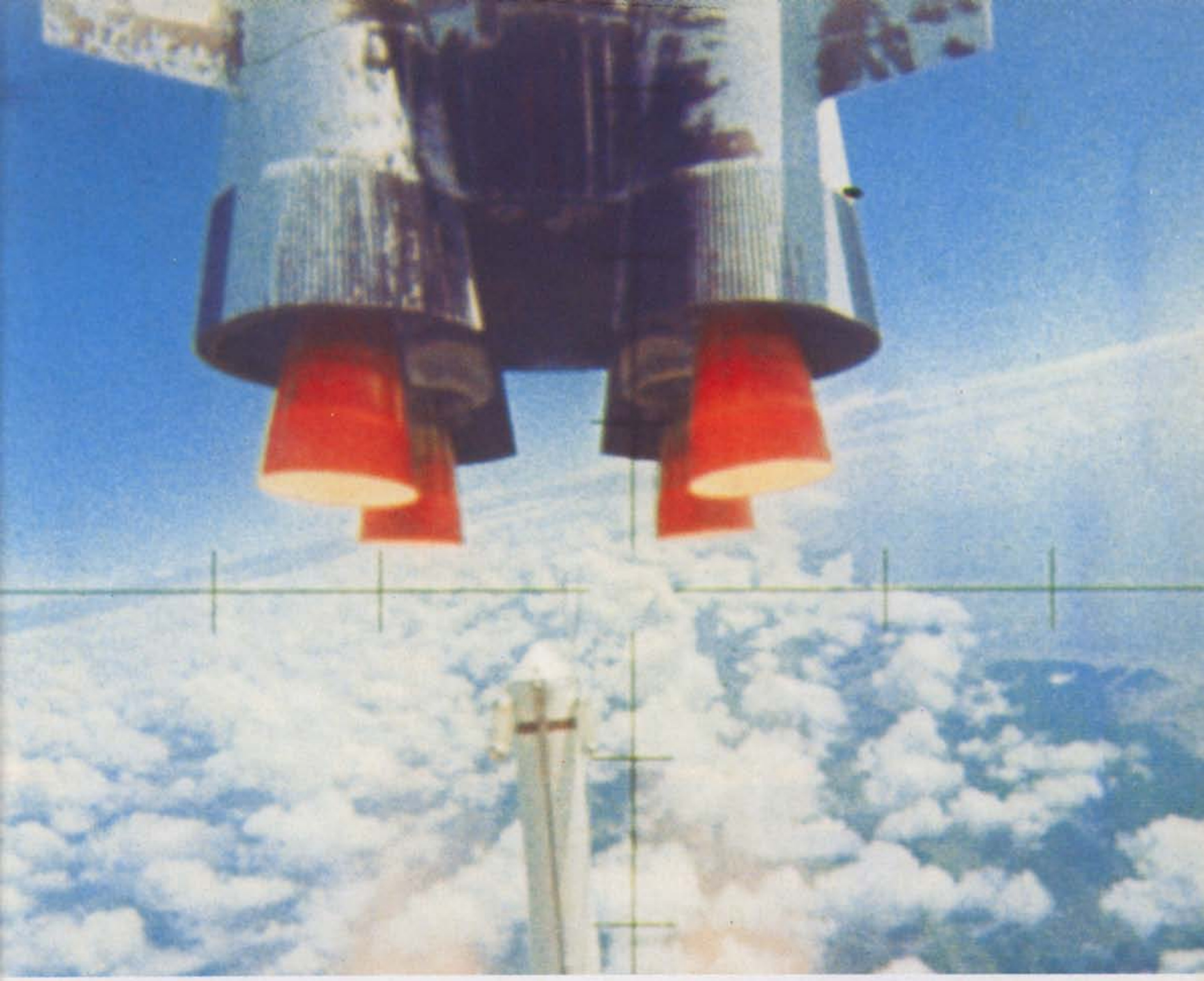

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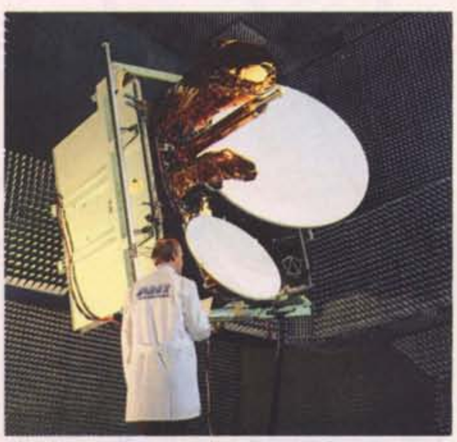

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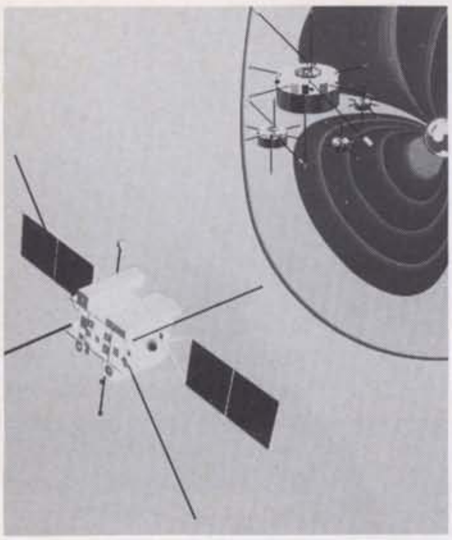


The Solar-Terrestrial Science Programme

K.-P. Wenzel, V. Domingo & R. Schmidt, ESA Space Science Department, ESTEC, Noordwijk, The Netherlands

In February 1986, the ESA Science Programme Committee (SPC) approved the Solar-Terrestrial Physics (STP) Cornerstone for inclusion in the ESA Scientific Programme. This event marked the beginning of the implementation of the Space-Science: Horizon 2000 element of ESA's Long-Term Plan.

In November, the SPC agreed to the implementation of the STP Cornerstone as a co-operative undertaking by ESA and NASA, which is now entitled the Solar-Terrestrial Science Programme (STSP). It consists of two space missions: 'Soho', the Solar and Heliospheric Observatory, and 'Cluster', a four-spacecraft space-plasma-physics mission. This programme is planned to be complemented by two Cluster-type spacecraft from the Soviet Academy of Sciences.

The prime objective of the STSP Cornerstone is to attack outstanding scientific problems in solar, heliospheric and space plasma physics in a unified and co-ordinated manner. The scientific payloads for both missions will be selected at the end of 1987, from proposals made by both the European and US scientific communities.

Launches for both missions are foreseen for 1994 and a minimum of two years of operations are planned.

Introduction

Solar-terrestrial physics is a major scientific discipline in space research. It can be thought of as encompassing the Sun as a variable star, the origin and transmission of the solar wind, the interaction of this solar wind with the Earth's magnetic field, and the subsequent time-varying effects in the Earth's atmosphere (Fig. 1).

The importance of understanding the complex processes that control and define the Earth's environment in space has long been recognised. Over more than a quarter of a century, a succession of space missions, supported by ground-based research, have explored the many facets of solar-terrestrial phenomena. Research in this field is a fundamentally multidisciplinary activity, pursued with increasingly sophisticated instrumentation; it demands expertise in solar, interplanetary and magnetospheric physics. The recognition that these individual disciplines have now reached maturity has led the scientific community to engage in a concerted attempt at a 'synthesis in solar-terrestrial physics'.

European scientific groups associated with programmes supported by ESRO/ESA and national agencies have played a significant and active role in the development of solar-terrestrial physics to date. Space missions such as ESRO-II, ESRO-I, Heos and Geos contributed to exploration of the near-Earth space environment that we now call 'geospace'. The joint ESA/NASA International Sun-Earth Explorer (ISEE) venture became the first multisatellite programme to study large-scale geospace phenomena. The ISEE spacecraft measured the position, velocity and geometrical features of plasma boundaries and other structures found in the geospace system and showed the importance of these boundaries for the energy-transport process. The ISEE programme also amply demonstrated that international collaboration is especially important and fruitful in this field of research.

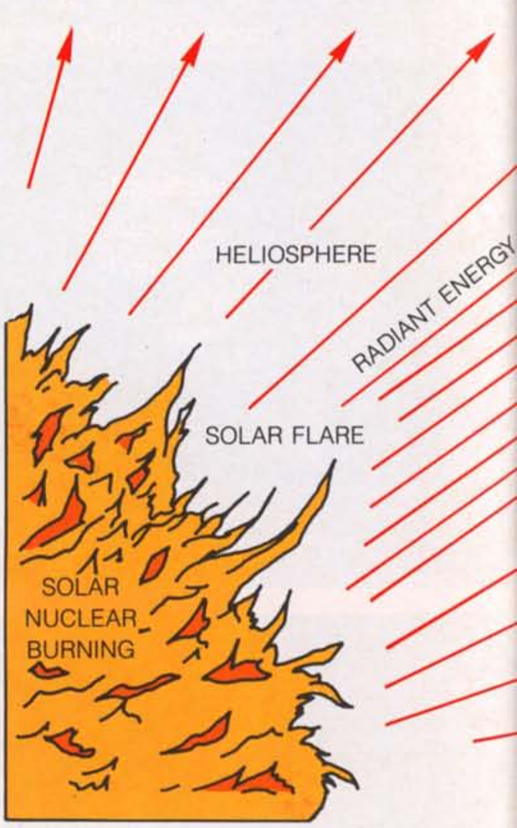
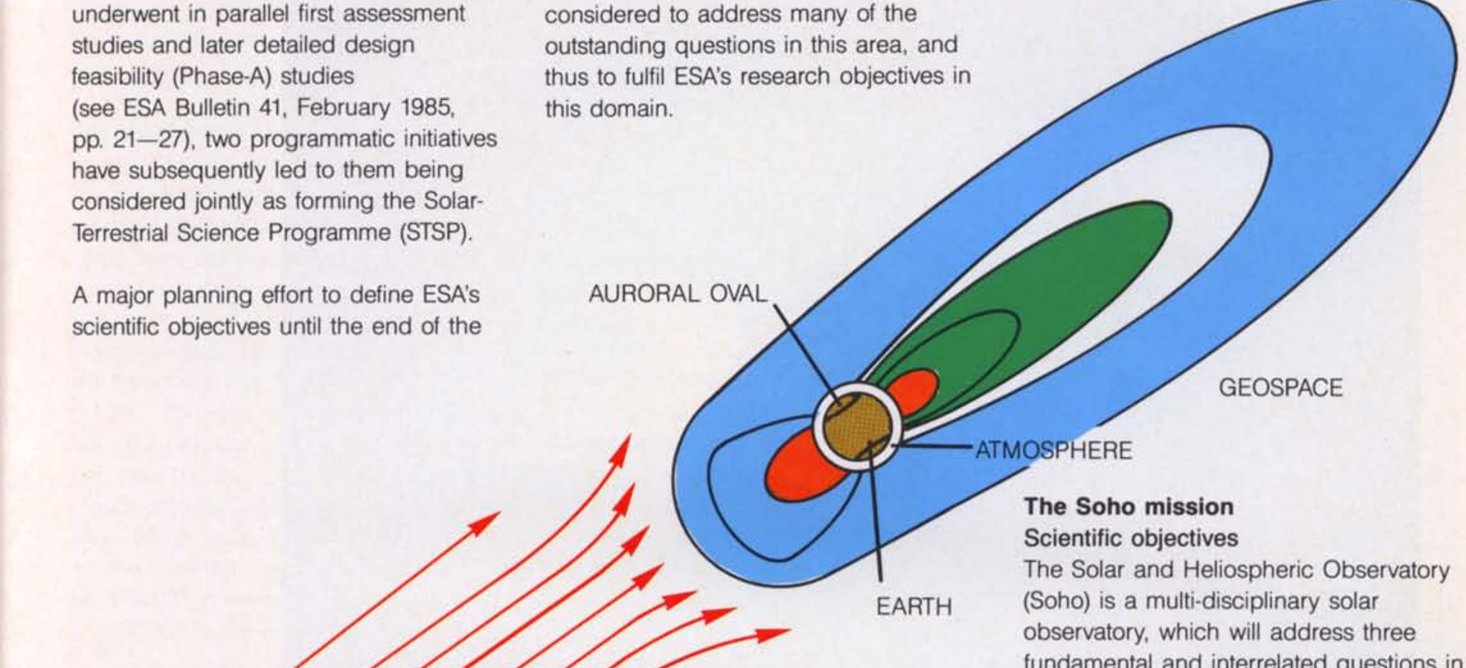


Figure 1 — The Sun, the geospace and Sun—Earth interactions



Reflecting the continuing interest of European scientists in solar-terrestrial physics, Soho and Cluster were proposed to ESA as independent missions in 1982. While the two missions underwent in parallel first assessment studies and later detailed design feasibility (Phase-A) studies (see ESA Bulletin 41, February 1985, pp. 21—27), two programmatic initiatives have subsequently led to them being considered jointly as forming the Solar-Terrestrial Science Programme (STSP).

A major planning effort to define ESA's scientific objectives until the end of the century led in 1984 to the programmatic framework called 'Space Science: Horizon 2000', which recognised solar-terrestrial physics as one of the four 'Cornerstones'. Soho and Cluster were considered to address many of the outstanding questions in this area, and thus to fulfil ESA's research objectives in this domain.

At the same time, planning of the International Solar-Terrestrial Physics (ISTP) programme was initiated jointly by the European, American and Japanese space agencies, to coordinate the activities of these partners for a total of six space missions to be launched in the early 1990s and covering a wide range of objectives in this field. Again, Soho and Cluster were considered to contribute significantly to the proposed set of scientific objectives.

Joint studies on the Soho and Cluster missions were undertaken with NASA during and after the detailed design feasibility study phase with the aim of ensuring completeness in the scope of the science to be addressed and, at the same time, of containing the cost to ESA within the limits set for the Cornerstone Programme. These studies led to the cooperative STSP/Soho and Cluster initiative.

The Soho mission
Scientific objectives

The Solar and Heliospheric Observatory (Soho) is a multi-disciplinary solar observatory, which will address three fundamental and interrelated questions in solar and heliospheric physics (Fig. 2):

- What are the structure and dynamics of the solar interior?
- Why does the solar corona exist and how is it heated?
- Where and how are the solar-wind streams accelerated?

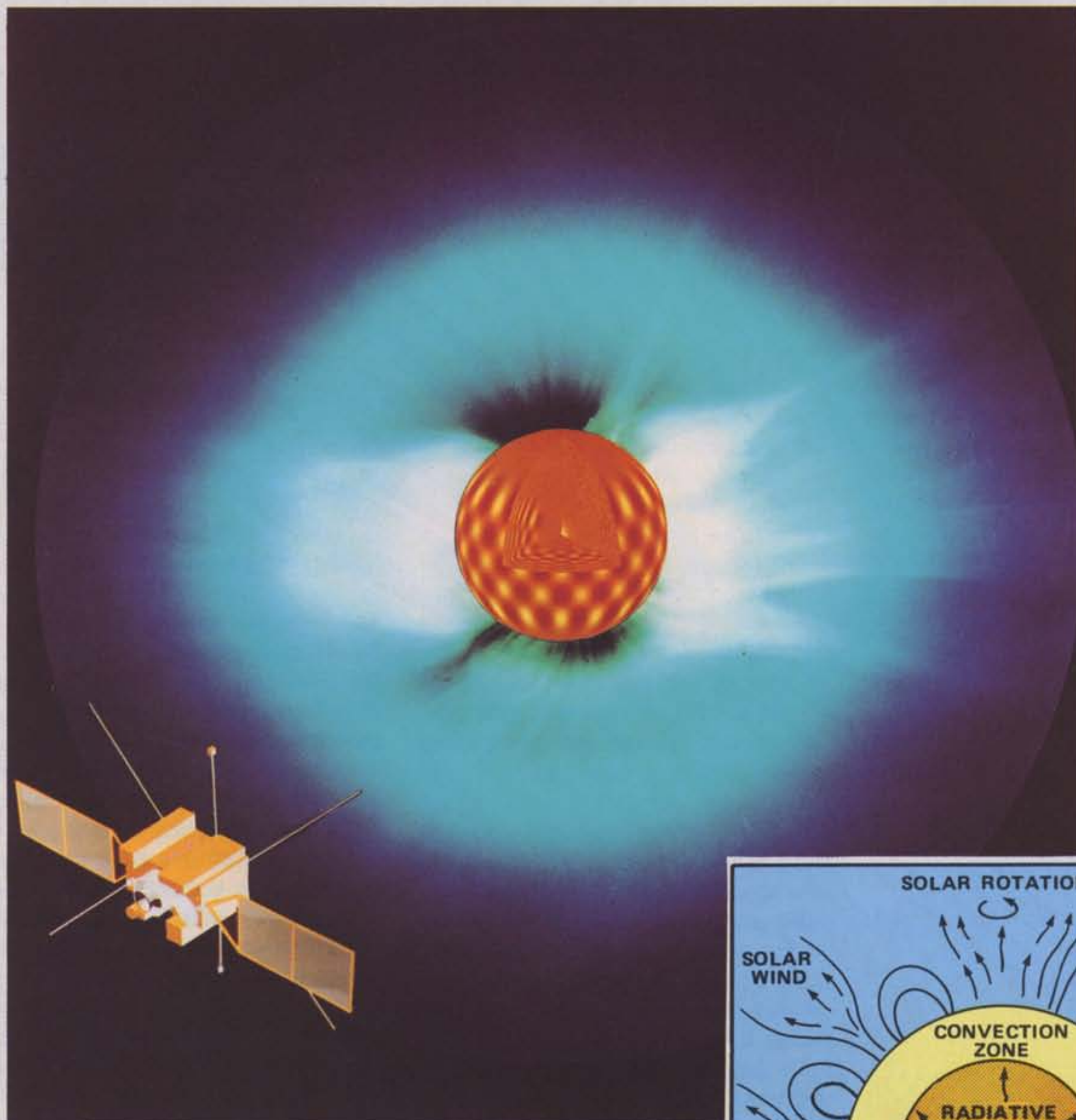
Answers to the first question will be sought from a recently developed branch of solar physics, known as 'helioseismology'. It relies on study of the Sun's internal structure (temperature and pressure) and dynamics by observing oscillations of the Sun's surface — similar to the use of earthquakes to infer the interior structure of the Earth (Figs. 3 & 4). A complete understanding of these oscillations would ultimately provide information about the Sun's interior composition and the dynamo processes that drive its eleven-year activity cycle.

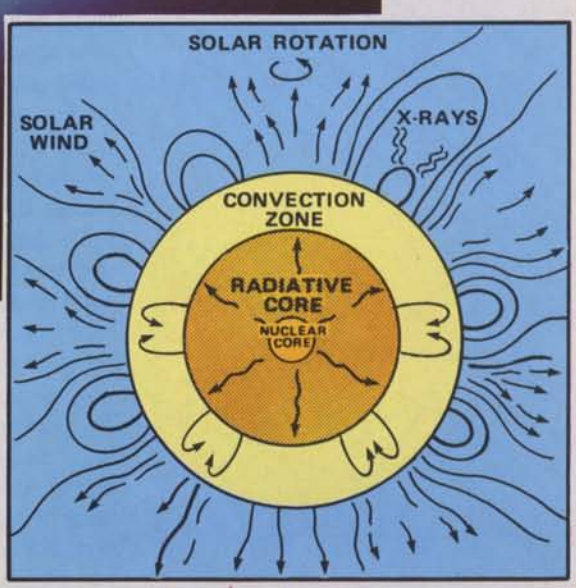
Short-term decreases (of the order of a few tenths of a percent in a few days) in solar luminosity occur with the

Figure 2 — Soho pointing towards the Sun. Contour plots of selected modes of solar oscillations superimposed on the solar surface. The inhomogeneous solar atmosphere, the solar corona, which is the source of the solar wind, is also shown

Figure 3 — Schematic of the interior structure of the Sun, including the core, where nuclear burning occurs, and the deep outer convection zone

Figure 4 — Power spectral analysis of the solar-plasma velocity variations, indicating solar oscillations with a frequency of 3 mHz, or about a 5 min period, coherent over regions of the order of 1/100 of the Sun's visible surface





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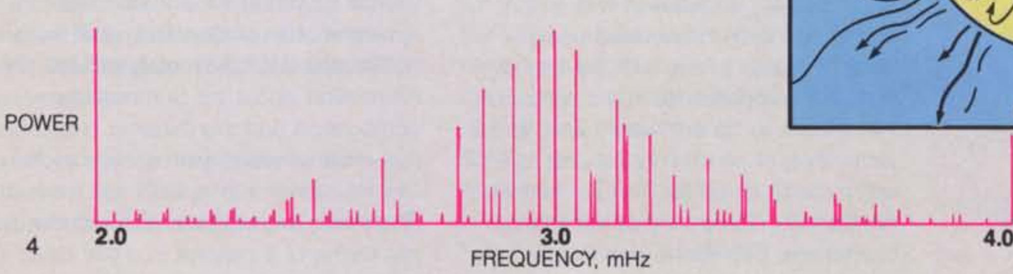

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Figure 5 — Extending from visible features on the solar surface such as sunspots are a variety of magnetic field structures. These structures in the solar atmosphere, called the corona, involve energetic atomic particles, light and X-ray emissions, and acceleration of the solar wind

appearance of large sunspots. It is therefore of great interest to study systematically the mechanism by which the Sun blocks, stores, and then ultimately releases this energy, and also to look for long-term trends (increases or decreases) that may be linked to the solar cycle.

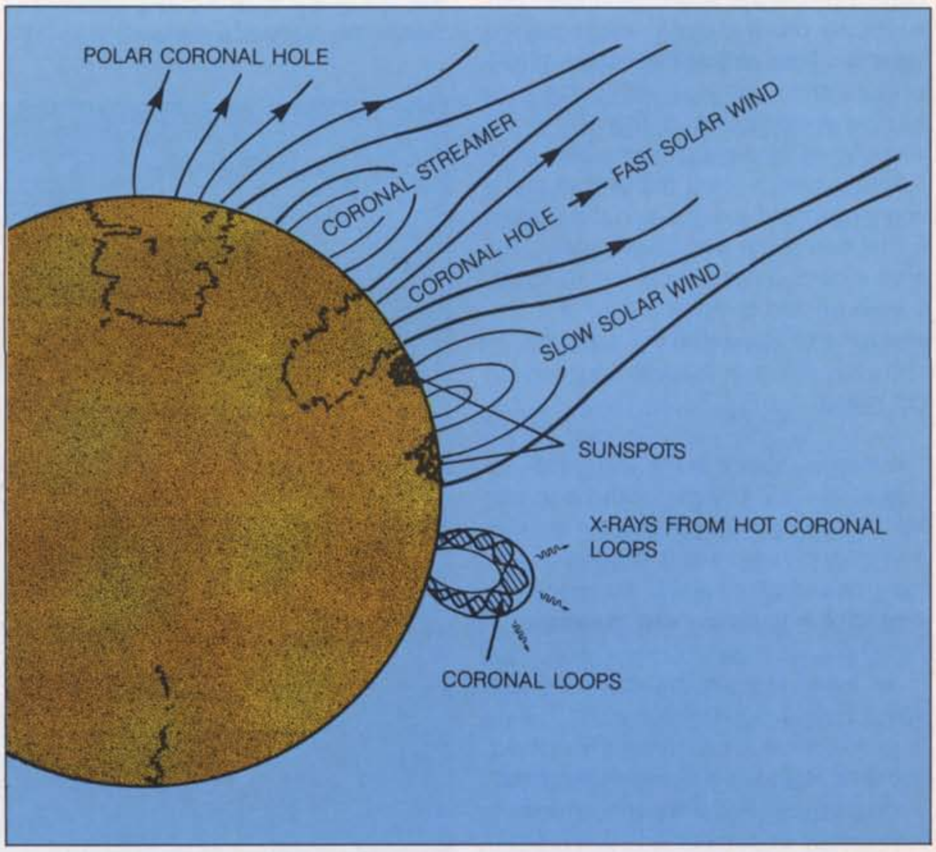
The second and third questions are strongly interrelated and involve studies of the physical processes that occur in the solar atmosphere. Its outermost layer is the solar corona — the pearly white halo of gas seen during solar eclipses (Fig. 2) — which generates the 'solar wind'. The latter is an invisible but extremely hot, high-velocity gas (or plasma) that is constantly being expelled from the Sun and streams out through the solar system. Just as the corona is highly irregular in shape, so is the solar wind. Measurements reveal that the temperature of the solar atmosphere rises from 5000° in the photosphere, to over 1 000 000° in the corona.

Observations of the Sun's surface and corona reveal a variety of features, including sunspots, solar magnetic flares, polar coronal holes, coronal streamers, and plasma jets (Fig. 5). Although these features are caused by the interaction of solar convection and magnetic fields, their interrelationship is still not well established. Spectroscopic measurements will be employed to derive the physical parameters of the solar plasma, such as its density, temperature, velocity and magnetic fields. These will then allow us to model plasma heating, solar-wind acceleration, and the transport of mass, momentum and energy from the solar photosphere up to the corona. These investigations need to be complemented by coronagraphic observations that can relate the fine structures observed in the inner corona to the larger-scale phenomena in the outer corona and solar wind.

In addition to these remote-sensing investigations, important information about the source regions of the solar wind in the corona can also be obtained by 'in-situ' observations at the spacecraft's orbit. This is possible because the solar wind is essentially 'collisionless' during most of its journey from the Sun. Field and particle investigations can therefore monitor it with highly improved time resolution, which will constitute an important step forward in the understanding of its small-scale plasma-physics phenomena.

Spacecraft design, orbit and operations
Soho will be a three-axis stabilised spacecraft, which will allow instruments to be pointed continuously at the Sun. It will consist of a dedicated payload module and a service module which will carry the spacecraft subsystems, the solar arrays and the magnetometer boom. The enormous size of the spacecraft (3.7 m in diameter and 3.6 m high) and its configuration are dominated by the anticipated size of some of the coronal instruments and the need to accommodate the propulsion system. The spacecraft's dry mass will be about 1350 kg, the propellant mass about 140 kg, and about 750 W of power will be available. Of these resources, the payload is allocated about 650 kg, 350 W and 40 kbit/s, with the possibility of a higher data rate for a solar-oscillation imager for certain periods of time. The high-accuracy and high-stability Sun-pointing design goals are 10 arcsec absolute pointing and 1 arcsec/15 min relative stability.

Soho is planned to be launched in October 1994 and will be injected into a halo orbit around the L1 Lagrangian point, about 1.5 million kilometres sunward from the Earth. The spacecraft will therefore be constantly in the solar wind, well outside the Earth's magnetosphere. Soho has a design



lifetime of two years, and will carry sufficient on-board consumables for an extra four years.

Soho's data will be recovered by NASA's Deep-Space Network (DSN) during three short (1.5 h) and one long (8 h) station pass per day. Scientific data acquired outside these periods will be stored on magnetic tape onboard the spacecraft and played back during the short station passes. A Science Operations Centre will be located at NASA's Goddard Space Flight Center to facilitate overall co-ordination and science planning operations. A European Science Operations Centre may be established at a later stage, if the necessary funding can be made available by the European scientific community.

The Cluster mission

The second STSP mission, Cluster, is dedicated to the study of space-plasma-physics processes. A plasma is an electrically charged gas in which each atom has been stripped of one or more of its electrons, leaving it with a net positive electrical charge. This assemblage of charged atoms and electrons carries mass, momentum and energy between the Sun and the planets. Exploration of the near-Earth space environment, or 'geospace', has revealed a dynamic and complex system of plasmas interacting with the magnetic fields and electrical currents surrounding our planet.

The magnetosphere is the volume of space dominated by the Earth's magnetic field. The solar wind compresses the day side magnetosphere and stretches the night side into a comet-like tail millions of kilometres long. Some solar plasma penetrates this magnetic shield and mixes turbulently with the local plasmas. When these 'magnetic storms' jolt the magnetosphere, charged particles stored in the tail region hurtle towards the Earth along magnetic field lines and release their energy as aurorae.

Cluster will investigate the physical processes that occur in key regions of the geospace in detail (Fig. 7). Such processes are by no means limited to the geospace, but are of a universal nature and occur in many astrophysical entities. The Earth's magnetosphere and its interaction with the solar wind is the closest and most accessible environment in which such processes can be studied in-situ.

The Cluster mission will be divided into two phases. An 'Equatorial Science Phase' involving one Cluster spacecraft will precede the primary four-spacecraft 'Cluster Phase'.

Equatorial Science Phase

Previous exploratory measurements in the Earth's geomagnetic tail, for example by the ISEE spacecraft, have revealed plasma flow, plasma storage, particle acceleration, and plasma wave generation processes participating in periodic global-scale reconfiguration of the tail (Fig. 6). Models of the reconfiguration process have been developed, but co-ordinated measurements by spatially separated spacecraft in the tail regions are required to reveal cause-and-effect relationships in order to further develop the models.

By using one of the Cluster spacecraft for an Equatorial Science Phase (ESP) mission planned to be conducted in conjunction with other missions of the International Solar-Terrestrial Physics (ISTP) Programme in the 1993 — 1994 time frame, a broad range of scientific objectives can be addressed. These include investigations of the transport and storage of different plasma populations (the main plasma sources of the geospace are the solar wind and the Earth's ionosphere) in the equatorial regions of the magnetosphere, and of the processes leading to the periodic reconfiguration of the geomagnetic tail.

Cluster Phase

The exploration of space plasmas has revealed that they have a tendency to

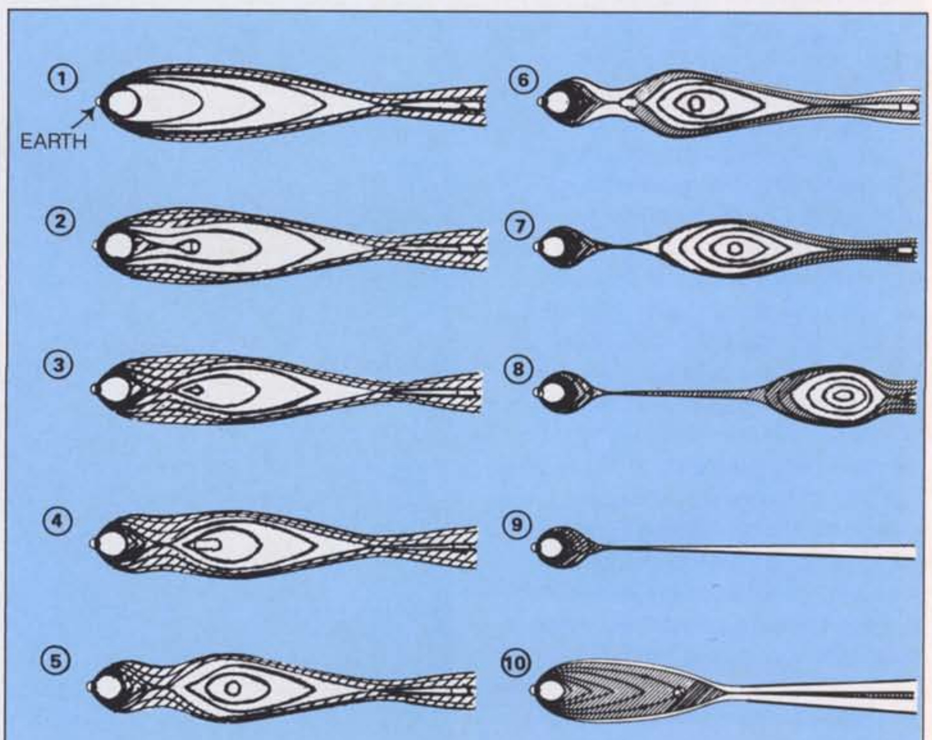


Figure 6 — Magnetotail reconfiguration

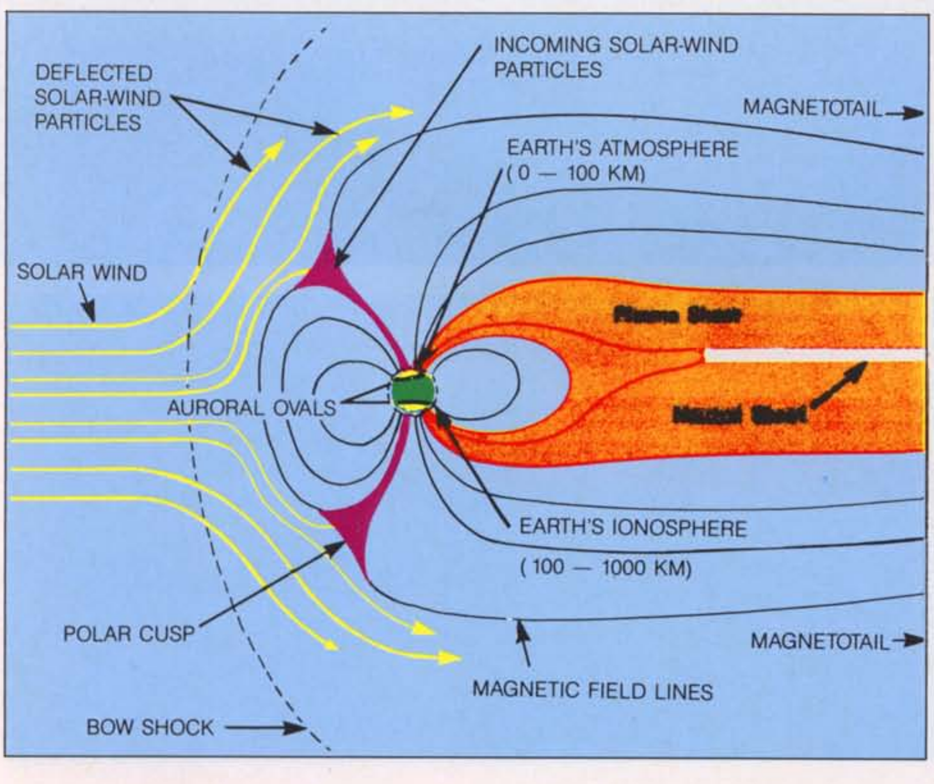
Figure 7 — Key regions of geospace

form small-scale structures. These can range from a few hundred to a few thousand kilometres in extent, and represent local concentrations of currents, electric fields or other characteristics in thin sheets or filaments, where the thresholds for the onset of certain micro-instabilities are easily exceeded.

The four-spacecraft Cluster mission has been designed to study the three-dimensional morphology and dynamics of such structures in key regions of the geospace. Understanding the transfer of mass, momentum and energy across boundaries between two different plasma regimes is believed to be fundamental for our understanding of the interaction processes between these regimes. Magnetic-reconnection or flux-transfer events at the magnetopause are typical examples of small-scale structures.

The technique of using several closely grouped spacecraft will be exploited to diagnose fine structures and to distinguish spatial from temporal variations. For this, a minimum of four non-coplanar Cluster spacecraft making measurements with high time resolution is required (Fig. 8). It is also necessary that the spatial separation between the spacecraft be adjusted to be comparable with the spatial scales of the phenomena to be investigated. Typical separations required will be in the range of a few hundred to a few thousand kilometres on the day side. Owing to the very large ion gyro radii in the plasma sheet, and because of the great interest in studying the somewhat larger characteristic scales of the dynamic structure of the tail, separations of up to a few Earth radii (one Earth radius equals 6370 km) are required on the night side and in the solar wind.

The four identical spacecraft will be instrumented to make comprehensive measurements of electromagnetic fields, plasma and energetic particles. The instrumentation on all four spacecraft will be largely identical in order to provide the requisite scientific homogeneity and to minimise spacecraft development costs.



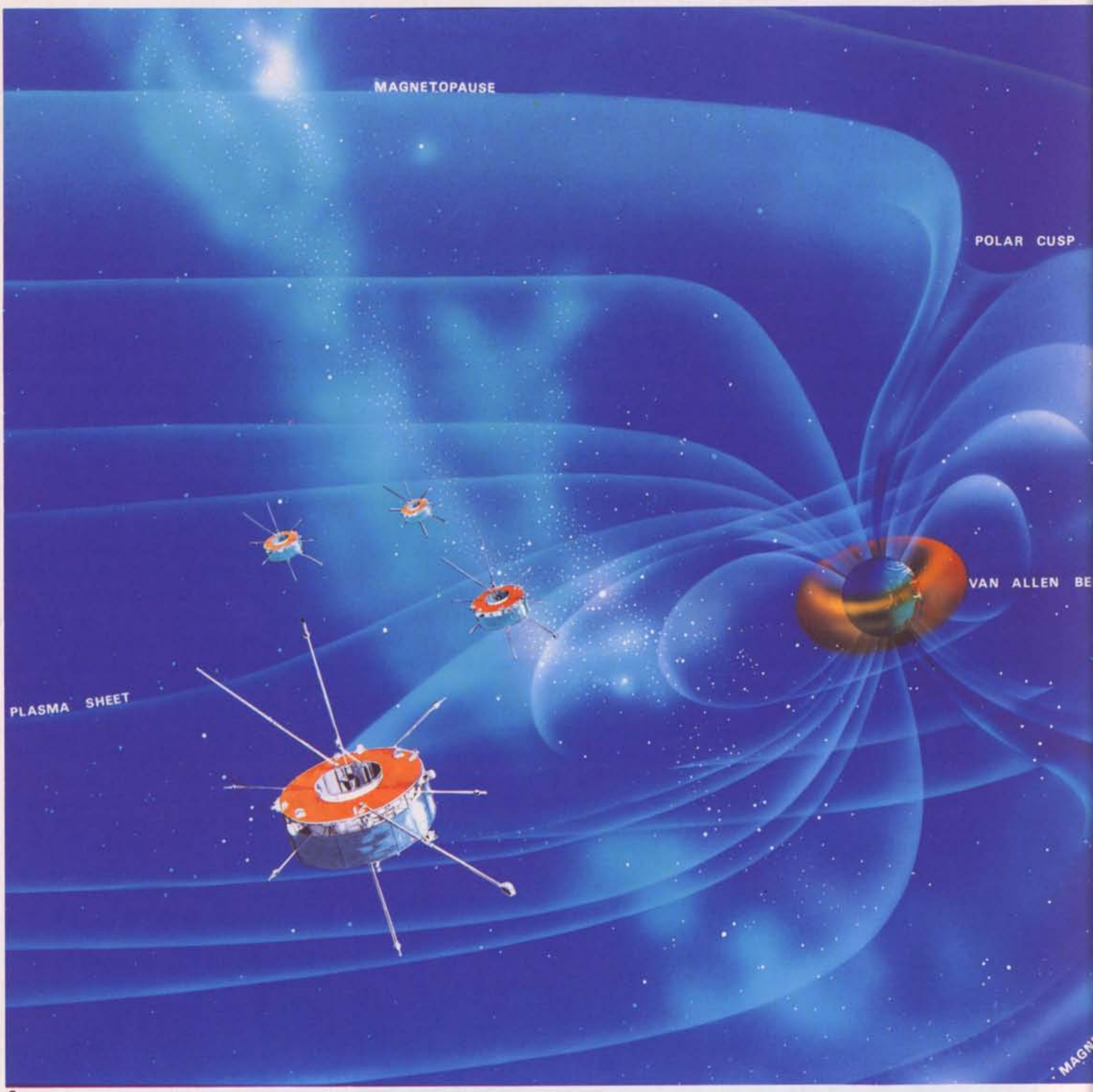
The eccentric near-polar orbit selected, with an apogee of 20 Earth radii near the equatorial plane, initially permits the traversal of practically all regions on the day side that are characterised by small-scale structures.

These are the bow shock and magnetosheath, the polar cusp, the medium-latitude magnetopause and the boundary layer (Fig. 9a). Six months later, the plasma sheet and the tail-current layer will be investigated (Fig. 9b). In between, the orbit will give low-latitude access to the morning and evening flanks of the magnetosphere, which are less well known but may play an important role in the process of mass transfer from the solar wind.

Spacecraft design, orbit and operations
The four identical spacecraft will be spin-stabilised (at 15 rpm). The spacecraft configuration is driven by the large orbit change required to achieve the Cluster operational requirements. The dry mass of each spacecraft will be approximately 425 kg, of which about 45 kg are foreseen for the payload, and the propellant mass 570 kg maximum.

Each spacecraft is cylindrical in shape, being approximately 2.9 m in diameter and 1 m high. It will have two radially deployable booms and two pairs of long wire antennas. The solar array will provide about 145 W of power, of which 47 W are foreseen for the payload. Electromagnetic-cleanliness considerations dictate the boom lengths (approx. 5 m), the geometrical and electrical layout of the solar array, and the conductive surface finish for all external spacecraft components.

The payload telemetry rate will be 16.8 kbit/s. In order to satisfy high time-resolution requirements, each payload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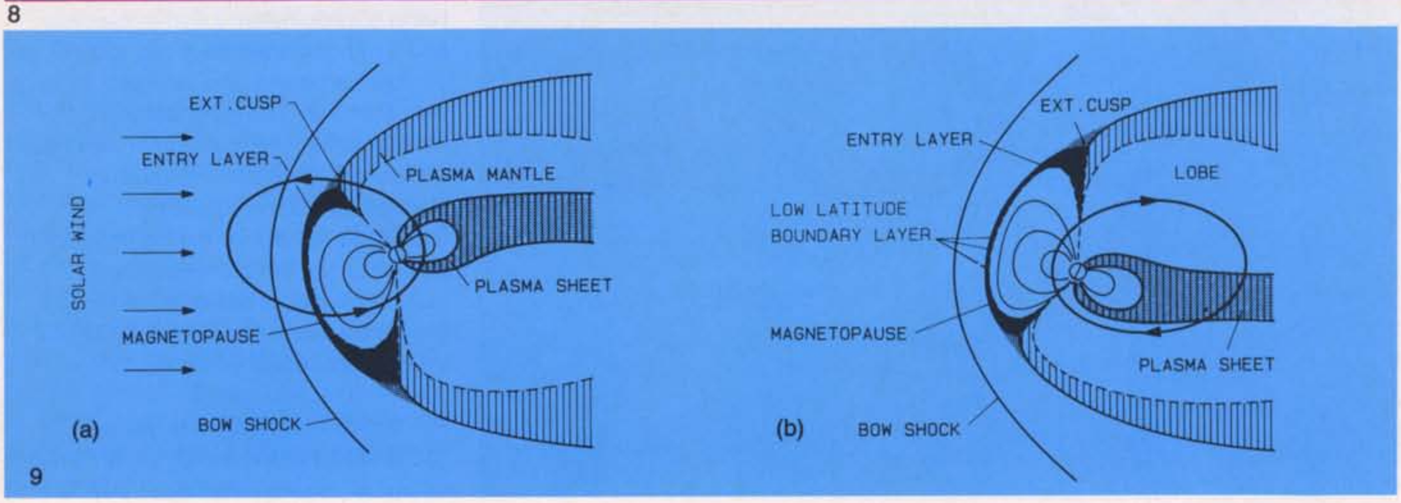
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BOUNDARY LAYER
MAGNETOPAUSE
PLASMA SHEET
BOW SHOCK
(b)

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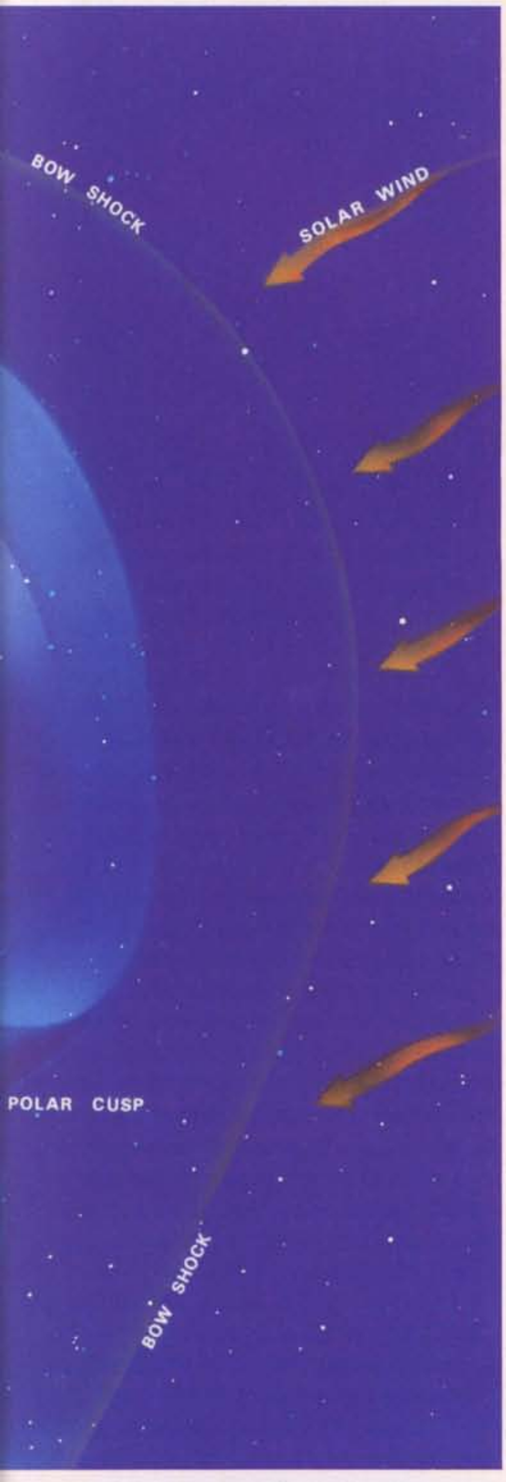


Figure 8 — The Cluster mission

Figure 9 — Cluster orbit in relation to the magnetosphere on the sunward side (day side) (a) and on the night side six months later (b)

will be able to generate a data rate as high as 100 kbit/s. These data streams will be routed into so-called 'burst memories' and dumped to ground later.

The first Cluster spacecraft should be available to NASA for launch, into an elliptic, equatorial orbit with an apogee of 12 Earth radii, in the first half of 1993. It will then undertake the ESP mission for about 18 months. The remaining three spacecraft will be launched into polar orbit by the second Ariane-5 test flight in October 1994. They will then be joined by the first spacecraft, to complete the four-spacecraft Cluster fleet. The nominal duration for the Cluster mission is two years. Attention will have to be paid to the implications of the radiation environment for the required lifetime of 3.5 years.

Different ground data-handling systems are planned for the ESP and the Cluster mission phases. NASA's Goddard Space Flight Center will be responsible for operations and data dissemination during the ESP. ESA's European Space Operations Centre (ESOC) will take over these responsibilities during the Cluster mission phase. During both phases, raw data will be supplied to investigators on tape or optical disk. The most recent data will also be accessible by remote access.

STSP: Common scientific objectives

There are many basic physical phenomena in common in the widely different environments of the Sun, the heliosphere and the Earth's magnetosphere. This was recognised in the synthesising effort initiated by ESA's Space Science: Horizon 2000 Programme, which led to the STSP Cornerstone concept. The strengths of the scientific arguments for a joint approach to solar-terrestrial physics to be undertaken by the Soho and Cluster missions were carefully examined and fully endorsed by the scientific communities behind these missions, during the ESA Workshop on Future Missions in Solar, Heliospheric and Space Plasma Physics, in Garmisch-Partenkirchen in May 1985 (Proceedings published as ESA SP-235).

Despite the different techniques used in studying the Sun and space plasmas, many phenomena occurring in solar and magnetospheric plasma physics, such as reconnection processes, plasma waves, and wave–particle interactions have been recognised as being similar or closely related. Therefore, beyond the respective scientific objectives of the two missions, these topics are particularly well suited for joint study with Soho and Cluster.

The unique opportunity provided by these two missions for cross-fertilisation between the disciplines of solar physics, space plasma and magnetospheric physics, which have evolved separately and are now mature enough to join forces for further scientific advancement, was substantiated during the Garmisch Workshop. The merger of Soho and Cluster into a single Solar-Terrestrial Science Programme is expected to provide a scientific return far greater than the sum of the two parts.

International collaboration

Although the wish to continue the fruitful scientific collaboration in solar-terrestrial physics between the European and American scientific communities already existed, the budgetary uncertainties that have plagued NASA's future space-science programme in recent years precluded concrete joint STSP planning. Only within the last twelve months, with the steady progress of the ESA studies, could firm plans for international co-operation be established.

The STSP as now planned involves major contributions from NASA, and a complementary contribution to Cluster from the Institute of Space Research (IKI) of the Soviet Academy of Sciences. Within ESA, the Programme is subject to tight financial constraints and its implementation will involve constant financial scrutiny and strict cost control.

The proposed STSP collaboration with NASA is based on programme contributions by ESA and NASA that will be shared in the approximate ratio of 2:1. For Soho, ESA will develop the spacecraft and NASA will provide the launch, flight operations and data dissemination. For Cluster, ESA will develop up to four flight spacecraft, the first of which will initially perform the Equatorial Science Phase (ESP) mission. NASA will launch and operate the ESP mission, while ESA will launch the remaining three spacecraft and then be responsible for operating the complete Cluster mission. NASA will be responsible for data dissemination during the Equatorial Science Phase, and ESA during the Cluster Phase. The STSP collaboration has to be confirmed by agreement on an ESA/NASA Memorandum of Understanding no later than 1 October 1987.

Bilateral discussions are continuing between ESA and IKI to explore the latter's possible cooperation in the Cluster mission with two spacecraft, with a view to augmenting the scientific return. The spacecraft would be designed, built, launched and operated by IKI; however, close co-operation with ESA would be pursued to ensure that they would be fully compatible with the prime scientific aims and technical requirements of the overall Cluster mission. It is anticipated that there would also be flight opportunities on the IKI spacecraft for European instrument groups involved in the Cluster mission.

Presently, IKI is investigating the possibility of putting one spacecraft into the deep tail, and the second into a Cluster-type orbit that would take it very close to a region of the magnetosphere of particular interest. Elsewhere it would be several Earth radii away from the Cluster spacecraft.

The plans of the Japanese and US space agencies for the other elements of the planned International Solar-Terrestrial Physics (ISTP) Programme (see ESA Bulletin 41, February 1985) have also matured. 'Geotail', a mission to provide measurements in the Earth's geomagnetic tail, was approved in 1985. It will be conducted by Japan's Institute for Space and Astronautical Science (ISAS). NASA is seeking approval this year for the Global Geospace Science (GGS) missions. These will include the 'Wind' spacecraft designed to monitor the solar wind in the region between the bow shock and the L1 Lagrangian point, and the 'Polar' spacecraft, to be placed in polar orbit, conducting both in-situ and remote-sensing measurements of polar-cusp and auroral processes. These measurements will be coordinated with data from the Chemical Release and Radiation Effects Satellite (CRRES), which will monitor radiation-belt dynamics. The ESP mission will provide complementary data to these missions for investigating the plasma flows and dynamics of the terrestrial magnetosphere.

Data processing and dissemination

A particularly important element of the STSP will be the provisions that need to be made for handling the data collected by the numerous spacecraft. To attack the scientific problems successfully and to accomplish the objectives of the STSP, investigators will need to be able to combine and compare easily measurements obtained with multiple instruments and from multiple spacecraft.

This will apply particularly to the four-spacecraft Cluster mission, whose scientific results will depend crucially on the handling scheme established for the extensive and comprehensive set of field-and-plasma data emanating from all four spacecraft. For other areas also, such as the solar-dynamics investigations and correlative studies between the Equatorial Science Phase of Cluster and Geotail, the ground-based data handling and exchange will be very critical. The Space Science: Horizon 2000 Plan that established the STSP Cornerstone recognises that: 'A special effort will be required to prepare for the operations and data handling of multi-spacecraft missions'.

Provision of the bulk data to investigators via hard media (optical disk, magnetic tape) and exchange and accessibility of data subsets by electronic means are presently foreseen. Summary data files composed of key parameters extracted from the data stream of each instrument are also planned. These data summaries will be used by investigators to identify particular events or times of interest that are candidates for detailed processing and analysis.

The whole topic of ground-based data handling and dissemination will require major attention by the agencies and the investigators during the design and development phases of the Programme. Detailed procedures for the data exchange within the STSP and with other solar-terrestrial missions will need to be agreed upon by the Science Working Teams composed of selected scientific investigators.

Conclusion

The Solar-Terrestrial Science Programme, encompassing the Soho and Cluster missions, will provide a major thrust in attacking scientific problems in solar, heliospheric and space plasma physics in a novel and unified manner. It is expected to permit systematic planning of the transfer of knowledge and understanding from one astrophysical system to another. This cross-fertilisation between the different disciplines involved will be essential to the Programme's scientific success.

The STSP's scope and capabilities have increased substantially since it will be conducted within an enlarged international venture. This will be the first time that the major space organisations have pooled their efforts right from the planning stage in the development of a large space programme for coordinated investigations of the relations between solar phenomena and the near-Earth environment.

Giotto: One Year On*

Prof. R. Lüst, Director General, European Space Agency

A year ago, here in this room, we witnessed the encounter of the Giotto spacecraft with Halley's Comet. After five years of spacecraft design, development, integration and testing, and after eight months of interplanetary flight, Giotto finally arrived at the comet. All of these efforts culminated in the last hours when Giotto entered the Halley atmosphere and even more so in the last minutes when the camera resolved the nucleus.

I will never forget the excitement in the last seconds when the telemetry link was suddenly interrupted and the nucleus images disappeared from the screens. Could a small dust particle impacting on the million times heavier spacecraft have ended the mission? Half an hour of anxiety ensued before the telemetry link could be re-established. The spacecraft and most experiments had in fact survived the encounter and scientific data were subsequently obtained for many more hours after closest approach.

ESA's first encounter with a solar-system object in interplanetary space was indeed truly exciting in that we could be present and watch in real time as the scientific data were obtained. But in fact it was a lot more.

There are four main reasons why this will surely be the most significant space-science event for Europe in this decade. First, and most importantly, we obtained substantial new scientific results. We clearly detected the comet nucleus, that celestial potato with its cratered black surface hidden behind bright dust jets; we confirmed the expectation that comets consist mostly of water ice and snow; we found out how much gas and dust is blown off from the nucleus every second; we analysed the size and composition of thousands of dust particles; and we investigated the whole range of plasma-physical phenomena resulting from the interaction between the cometary and solar-wind plasmas. All instruments onboard the spacecraft worked well and we can now say confidently that we achieved all the scientific objectives set out in 1980 when the Giotto mission was approved.

Secondly, Europe successfully demonstrated its capability to manage a complex technical system, and on a World stage. The encounter was transmitted live by 56 television stations, representing 37 countries around the World. An estimated 1.5 billion viewers witnessed the 'Night of the Comet' on television, not to mention all the live radio broadcasts and newspaper articles the next morning.

The spacecraft's design and development was managed by a relatively small Project Team at ESTEC, which interfaced with 130 Experimenters from 11 different countries, with ESOC, with the Star Consortium, with Arianespace, Intespace and CNES, with NASA, and with CSIRO in Australia. The spacecraft was built by the Star Consortium with the participation of 20 companies from 10 European Countries.

The ground segment, managed by ESOC, brought together a most impressive array of ground stations of varying sizes and belonging to various organisations from around the World. These elements had never been brought together before, and everything had to run like clockwork during the night of the encounter.

Thirdly, the Giotto mission can be held up to the doubters as a convincing example of the benefits of European collaboration. By pooling their resources, the Member States have together achieved something that each nation alone could certainly not have achieved.

The fourth reason why Giotto will go down in history as an important milestone in space science is the emphasis that it has brought to global cooperation. Through its Giotto project, ESA played a key role in the Inter-Agency Consultative Group for Space Science, or 'IACG'. The IACG members — Intercosmos, the Japanese ISAS, NASA and ESA — sent a total of six spacecraft to Halley, and we can proudly say that Giotto represented us well. ESA also participated in and supported the International Halley Watch, or 'IHW', the ground-based counterpart of the IACG. The IHW coordinated some 1000 professionals and 5000 amateur astronomers from over 50 countries.

* Presentation on Friday 13 March 1987, at the European Space Operations Centre (ESOC) in Darmstadt, Germany on the occasion of the First Anniversary Celebration of the Giotto Encounter with Halley's Comet.

Together, the IACG and the IHW formed the cornerstones of a global effort to explore Halley's Comet. It was the largest space-science campaign ever undertaken.

In its wake, there is a new spirit now among the leading space agencies in the World, a spirit of cooperation rather than of competition. The importance of the IACG was clearly recognised by the Pope when he granted us the Audience on 7 November 1986. On that occasion he called the experimenters associated with all of the Halley missions 'peacemakers'.

I am happy to tell you that the four member agencies of the IACG have since agreed to continue their cooperation beyond the Halley missions by adopting a new, even more ambitious project in Solar-Terrestrial Science, involving some 20 spacecraft.

Giotto's great success was only possible through the dedication and hard work of many people working in a variety of areas. I am particularly happy to see two groups of people here today who contributed very significantly to the mission's ultimate success: the scientific Experimenters and the ESOC experts.

I have expressed my thanks to the Experimenters on an earlier occasion, in Paris on 15 May last year, when the first results of the encounter, published in a special issue of Nature, were presented to the Press. Today, I would like to take the opportunity of this First Anniversary Celebration to thank the ESOC experts.

During the final critical hours and minutes of the encounter, the ESOC Team had to continue to concentrate in the tense atmosphere of the Control Rooms, while the rest of us could enjoy watching the mysteries of Halley unfold. In the months before the encounter, they steered Giotto painstakingly towards its target whilst keeping its high-gain antenna pointed at the Earth. That the

Figure 1 — Members of the ESOC Team and the Giotto Experimenters with Mr Kurt Heftman, ESA's Director of Operations (extreme left), Prof. Reimar Lüst, ESA's Director General (front row, third from left) and Dr Roger Bonnet, ESA's Director of Scientific Programmes (front row, fourth from left).

Pathfinder Concept was so successful is due in large part to their efforts and patience, with interfaces that were not always easy.

The operations experts, a small team that had to put in many extra hours, not only showed great competence in the operation of the spacecraft, but also considerable flexibility in meeting frequently changing scientific requests. Thanks to their endeavours, the scientists got a lot more out of the mission than was originally foreseen.

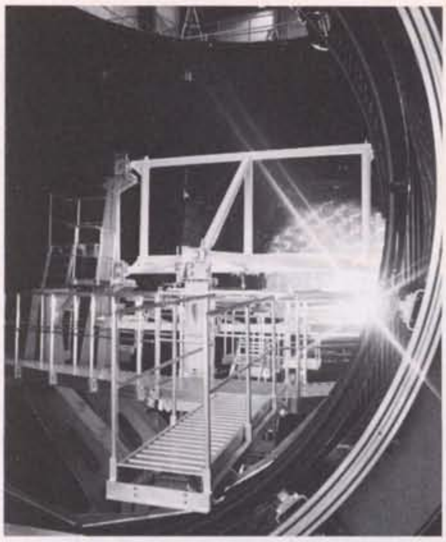
Nor must we forget the ground-station engineers, who managed to put an impressive ground-station network together, tailored to the needs of the Giotto Project, including conversion of the Parkes 64 m antenna to an operational deep-space station.

Nor must we forget the scientific data-processing engineers who processed and distributed the data so rapidly, enabling the experimenters to publish their results in record time. This again contributed significantly to Giotto's success.

Let me add my congratulations to those of the Experimenters in thanking the ESOC Team for its outstanding performance and cooperative spirit.

We have just heard from Dr. Rudeger Reinhard, Giotto's Project Scientist, that the spacecraft will be re-activated towards the end of 1989 and that there might be a chance of another cometary encounter. We should do our utmost to achieve this. It would indeed be a remarkable double if Giotto could encounter Comet Grigg-Skjellerup in July 1992 and pass very near the nucleus.

In the meantime, we can be proud that ESA has been able, in the joint effort with NASA, with Intercosmos and with ISAS, to demonstrate what can be done for science if we work together around the globe.



The European Large Space Simulator Comes into Operation

P. W. Brinkmann, Test Services Division, European Space Research and Technology Centre (ESTEC), Noordwijk, The Netherlands

On 14 January 1987, Dr. R.W. de Korte, Dutch Vice Premier and Minister for Economic Affairs, formally inaugurated the new Large Space Simulator (LSS) at ESTEC (Fig. 1). The commissioning of the LSS completes the first phase in the implementation of an Integrated Test Centre for large satellites in Noordwijk. The Agency will henceforth be in a position to provide European Industry with a suite of large environmental test facilities, associated laboratories and support services, all housed under one roof. The advantages of this concept lie not only in the direct benefits of avoiding costly and risky transportation of expensive and vulnerable space hardware from one test centre to another, but also in the associated reductions in the overall project schedule and risk.

LSS concept and performance
The role of the LSS is to provide accurate simulation of the environmental conditions experienced by spacecraft in orbit (high vacuum, deep-space temperature background, solar radiation, etc.), thereby facilitating optimisation of the design and verification of both spacecraft/payload hardware and software.

The specific design features of the new facility, including the exceptional test volume available, and their excellent performance characteristics mean that a variety of crucial tests can now be carried out under high-vacuum conditions, including:.

— Thermal tests: solar simulation, infrared radiation, and vacuum temperature cycling.
— Mechanical tests: deployment of large structures, dynamic balancing, and photogrammetry for deformation measurements.

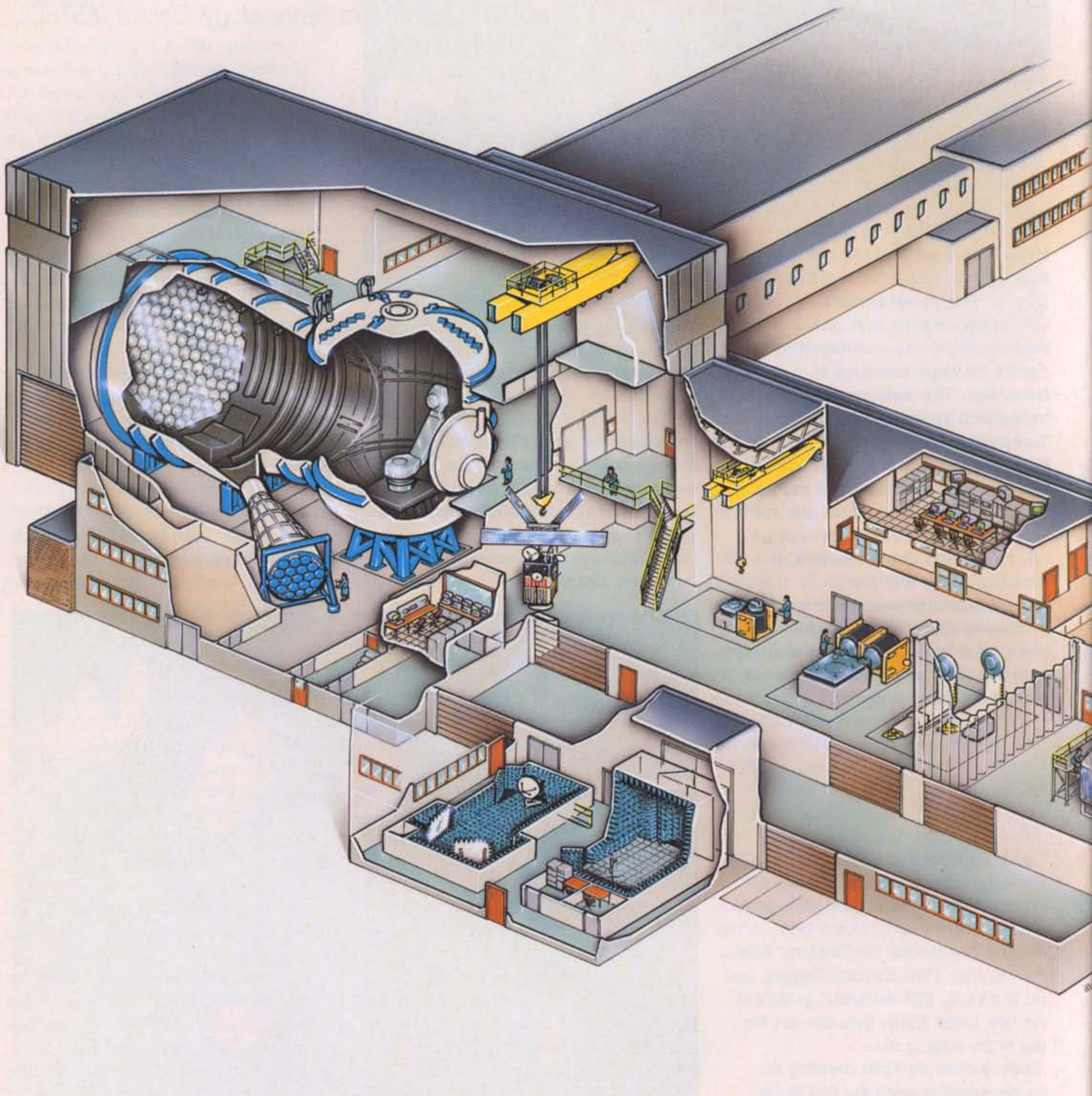
Subsystem monitoring and control are based on state-of-the-art technology and provide remarkable flexibility in selecting test-mode combinations and sequences tailored to user requirements.

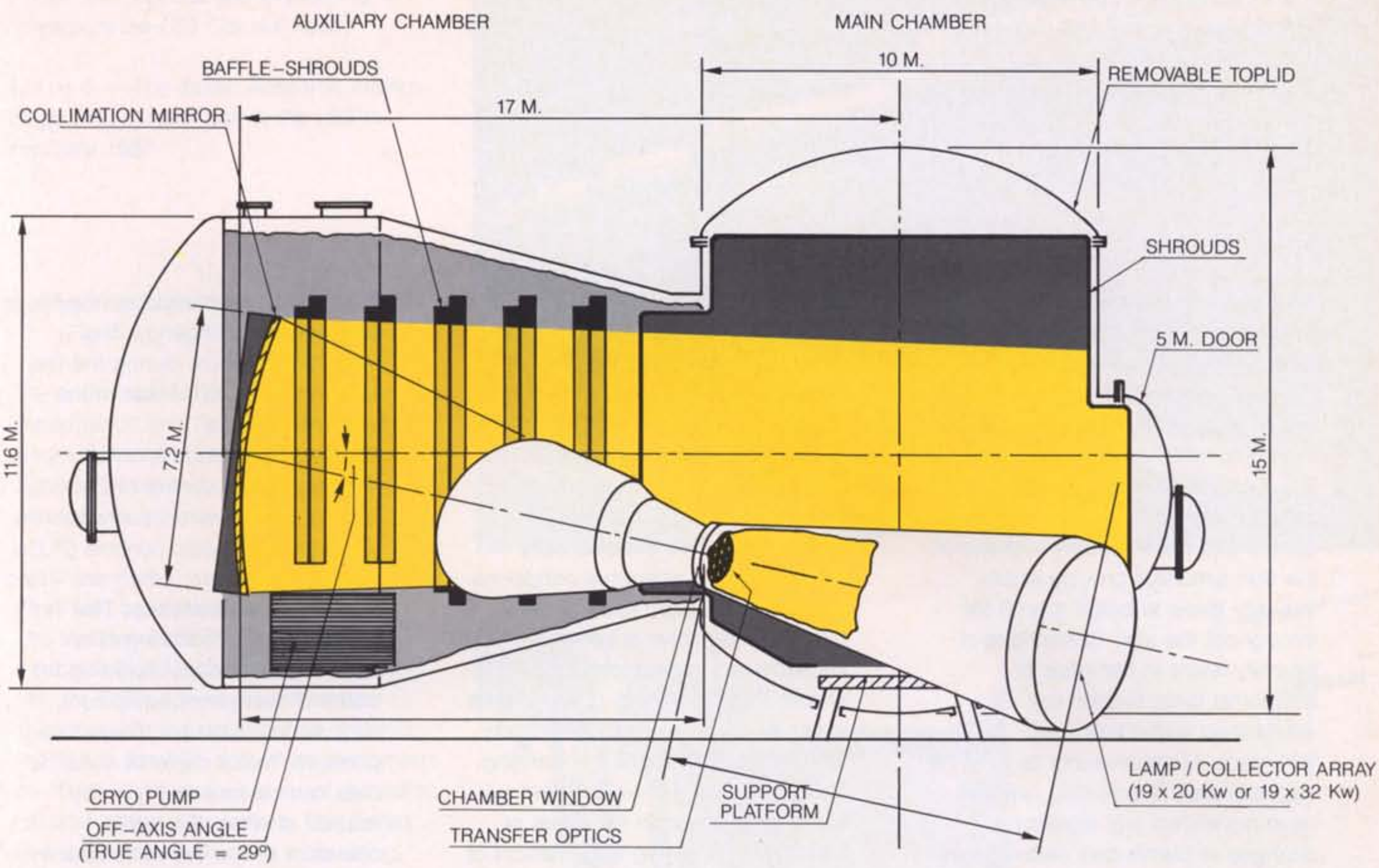
The layout of the Integrated Test Centre and the configuration of the LSS itself are illustrated in Figures 2 and 3, respectively.

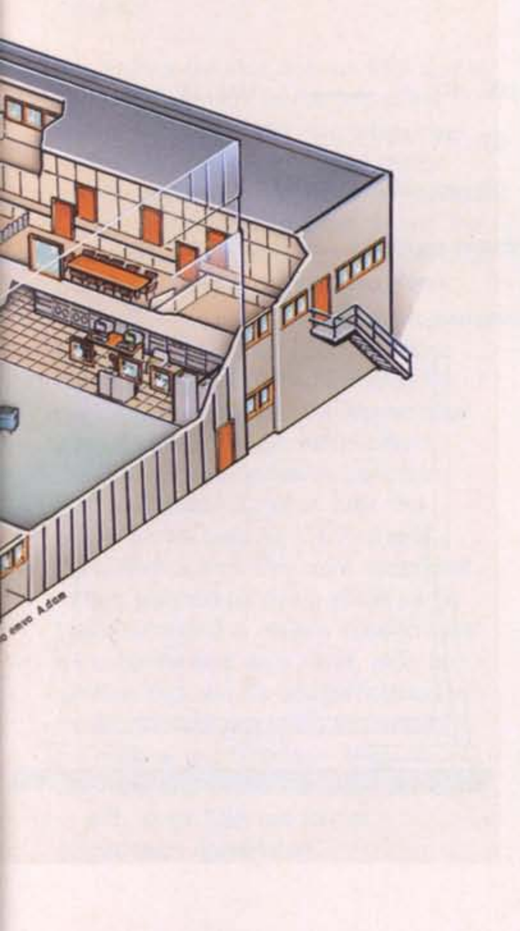
Figure 1 — From left to right, Mr. M. Le Fèvre, Director of ESTEC, Mr. P.W. Brinkmann, LSS Project Manager, Minister R.W. de Korte, Dutch Vice Premier and Minister for Economic Affairs, Prof. R. Lüst, ESA's Director General, and Dr. W. Ockels, ESA Astronaut, in front of the new Large Space Simulator on the day of the inauguration.
Inset, Minister de Korte pressing the master switch to bring the LSS to life.

Figure 2 — Layout of the Integrated Test Centre

Figure 3 — Schematic of the Large Space Simulator (LSS)







The items under test will be suspended in the main chamber, which has a diameter of 10 m and an overall height of 15 m. The overall length of the facility, including the main and the auxiliary chambers, is 25 m. The main chamber is equipped with a shroud lining its complete inner surface, while the shroud elements in the auxiliary chamber are in the form of baffles.

The collimation mirror is suspended from the rear stiffening ring of the auxiliary chamber. A quartz window, with a diameter of slightly more than 1 m and a thickness of about 8 cm, provides the interface between the vacuum chamber and the lamp-house . The lamp-house contains 19 lamp modules, collection optics and transfer optics and provides a protective nitrogen environment for all optical elements.

The test items are mounted on a vibration-free support platform via a motion simulator (presently being manufactured), or suspended from support lugs in the upper part of the main chamber.

In addition to the prime goal of achieving a high simulator performance in providing stable and reproducible test parameters, the design of the LSS was also geared to achieving an efficient facility in terms of test preparations and test operations. Knowing that the LSS is now a unique facility in Europe and therefore has no comparable back-up, the 'down-time' between tests needs to be kept to a minimum to avoid any unnecessary programme delays.

The acceptance tests and the first facility operations have shown that the performance of the LSS is very satisfactory indeed. In particular, the performance figures of the Sun simulator (SUSI) are well beyond expectations. Some of the features of the LSS that are of direct interest to potential users are:

— High Sun simulator efficiency: Only 12 of the 19 available high-power xenon lamps are required to achieve an illumination intensity of one solar constant in the reference plane (beam diameter 6 m). This provides high redundancy and the possibility of testing at elevated intensities.
— Uniformity of intensity distribution in the test volume: The intensity distribution in the test volume is

Figure 4 — Illumination-intensity distribution pattern in the LSS (reference plane)

characterised by very small local gradients right up to the edge of the beam. Figure 4 is a plot of the intensity pattern in the reference plane. It shows a uniformity of better than 3%, measured with a 2 x 2 cm^2 solar cell.

— Stability and reproducibility: The control and power-supply systems of the Sun simulator provide stable intensity levels to better than 0.5% throughout the test. Corrections of intensity levels in the case of accidental lamp failures are established within less than 200 msec. Measurements at approximately six-monthly intervals have not shown any significant changes in distribution pattern, even after lamp replacements.

— Operational safety: The Sun simulator is protected against accidental changes in intensity caused by operator error or failure of the control loop. Changes in the efficiency of the optics are also monitored to identify undue degradation. This enables early identification of abnormal conditions (e.g. contamination, misalignment, etc.) and corrective actions can be implemented immediately, both to ensure that the validity of test results is not jeopardised and to preclude safety-critical situations from arising. The cryogenic pumping system has a pumping speed in the order of 350 000 l/s, ensuring achievement of the requisite high-vacuum conditions with ample contingency. The operating pressure during the first test on the IRIS/STM was in the 10^{-7} mbar range.

— Facility control and reporting: Monitoring and control of the facility's performance is effected via programmable logic controls (PLCs) in each subsystem, which are linked to a dedicated computer. This system allows monitoring of all relevant facility data, including the status of subsystem equipment, such as temperatures, flows, valve positions, motor currents, etc. The data can be presented, at the request of either the facility operators or the experimenters, in

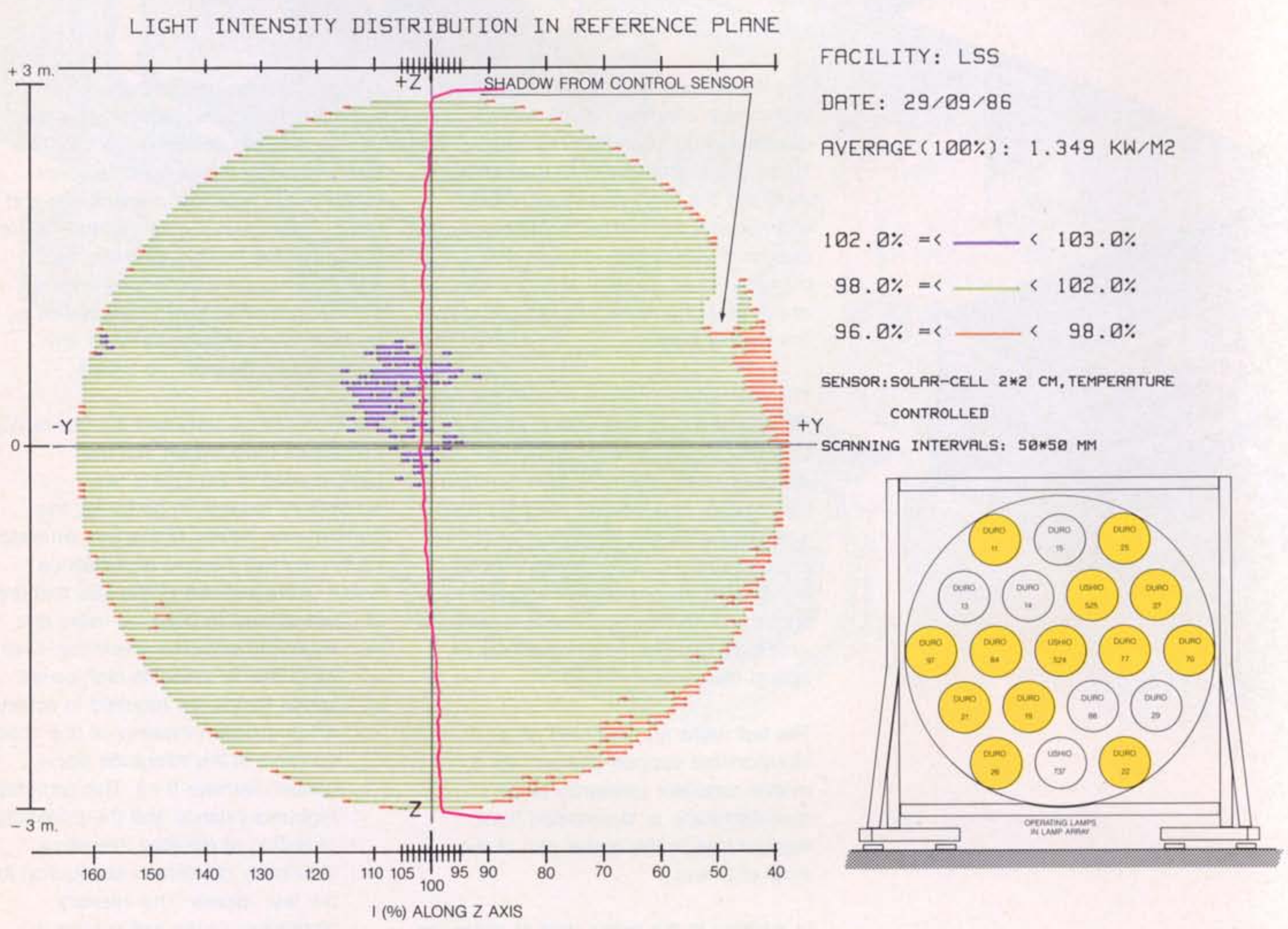
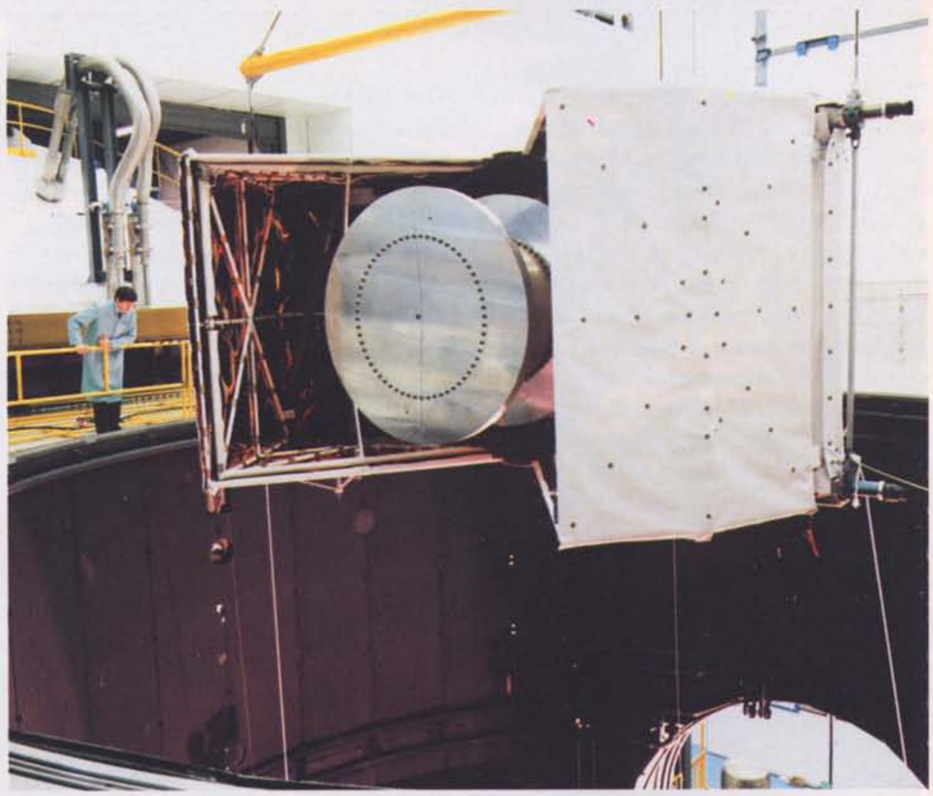


Figure 5 — Control and monitoring screens in the LSS Control Room

Figure 6 — The Italian Research Interim Stage (IRIS) under test in the LSS in February 1987



various formats on colour monitors (Fig. 5).

The combination of the LSS's outstanding performance and the high degree of automation of the chamber leads to significantly lower operating costs than were previously incurred.

First test operations

The facilities at ESTEC are at the disposal of all Member States, and not only for ESA's space programmes. Therefore, it is no coincidence that the first test in the LSS should be perfomed on 'IRIS', which is a product of the Italian national space programme. The Italian Research Interim Stage is a spinning, solid upper stage for deploying lightweight satellites weighing up to 900 kg from the Space Shuttle and boosting them into elliptical transfer orbits. Figure 6 shows IRIS inside the LSS, mounted on a Shuttle-cargo-bay simulator.

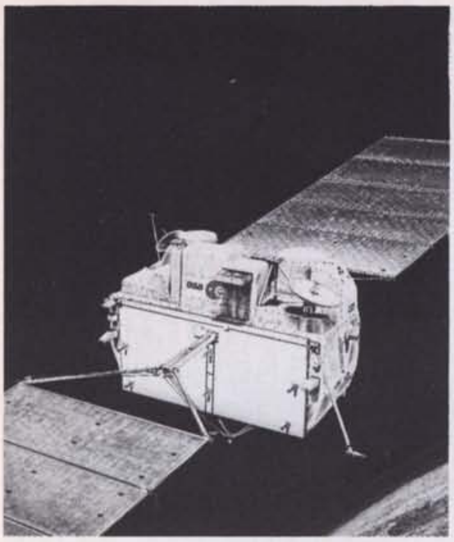
The thermal-balance tests on IRIS and its support equipment (consisting of the cradle, Sun shield and spin table) were performed to verify its thermal design and to validate the mathematical models. During this first thermal-balance test, the LSS operated to the complete satisfaction of the IRIS Project Team.

After the IRIS test, the LSS has been booked by MBB/ERNO (Germany) for deployment tests on a high-power solar array for the Space Communication Satellite Programme (prime contractor Ford Aerospace). Later in 1987, the facility will be used for the testing of ESA's Eureca and Hipparcos spacecraft. In fact, planned utilisation of the Large Space Simulator is already beyond initial expectations and, as a result, tests on satellites that can be accommodated in smaller facilities are being transferred to the national test centres — IABG in Germany and CNES-Intespace in France — with which ESA has formal co-operation agreements.

Outlook

As part of the ESA Investment Plan for Common Technical Facilities at ESTEC (ESA/IPC(84)53), the Integrated Test Centre will be further complemented in the coming years by expanding the Test-Preparation Areas and by adding a Large Acoustic Chamber and a Compact Payload Test Range. State-of-the-art analytical tools for supporting and complementing environmental testing are being developed in parallel. In particular, a Test-Data Analysis System is under development aimed at a significant reduction in the time required for the validation of theoretical models with experimental results. Ideally, this system should deliver data during the test campaign itself that enables almost on-line adaptation of test programmes and the testing out of corrective actions/procedures.

These additional facilities are expected to be available from 1989 onwards in order to extend the capacity of the facilities available in Europe. The 'Coordinated European Test Facilities' will then be suitably equipped to provide efficient support to European Industry in verifying that future satellites will indeed 'last the lifetime' for which they have been designed.



From Eureca-A to Eureca-B

R. Mory, Eureca and Spacelab Utilisation Office, Directorate of Space Station and Platforms, ESA, Paris

The Agency's Eureca carrier, development of which began at the end of 1984, will provide valuable early experience in the development, operation and exploitation of unmanned automated platforms in low Earth orbit. The initial carrier, Eureca-A, incorporates all the more attractive features of Spacelab and conventional expendable satellites. The later version, Eureca-B, will provide a substantial enhancement of these baseline mission capabilities.

The Eureca system
Eureca has been devised with the primary goal of providing a carrier for space payloads that will not only ensure the acquisition of valuable technological experience, but will also provide much-needed experiment flight opportunities for potential future Space-Station users.

The basic concept is one of a free-flying carrier of experiments to be launched and retrieved by the Space Shuttle. Eureca can be boosted to a height of about 525 km from the Shuttle's low-Earth orbit by its own propulsion system. Its orbital altitude will then decay slowly during the mission. At the end of its mission, Eureca will rendezvous with the Shuttle, to be retrieved and returned to Earth (Fig. 1).

Eureca's dimensions are chosen to be compatible with the size and weight of payload that can be economically developed in Europe. It combines the advantages of Spacelab — high mass and power capability, and recovery — with those of a free-flyer — extended operating time, and non-polluted environment (Fig. 2).

The fundamental framework of Eureca's primary structure (Fig. 3) consists of standardised high-strength struts and node elements (carbon tubes with inconel end-fittings) joined together to form the requisite number of 70 cm×70 cm×70 cm open box units. Eureca will weigh approximately 4000 kg at launch, about 1000 kg of this total being allocated to the payload. The carrier is 2.3 m long and has to fit into the Shuttle's 4.5 m diameter cargo bay. The system will be supported in the bay by two trunnions and a keel fitting.

The Eureca carrier's thermal-control system uses space-proven passive techniques combined with active heat rejection. A fluid cooling loop dissipates thermal loads into space via two radiator panels on the sides of the main structure. Experiments and equipment can be cooled either with cold plates or by fluid flowing directly to their interiors.

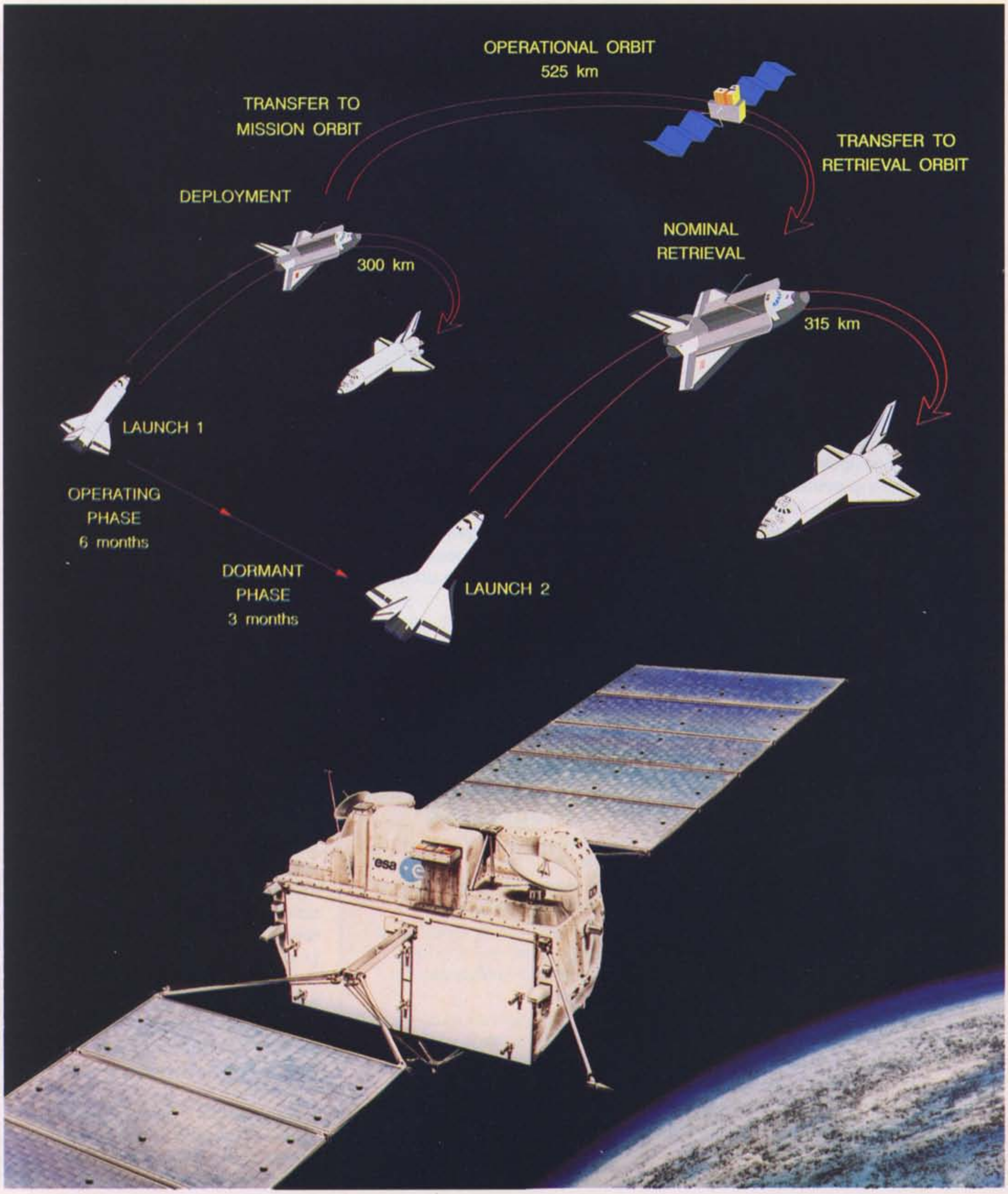
The electrical subsystem generates, stores, conditions and distributes 5300 W of power to all subsystem units and instruments. Two deployable and retractable solar arrays are used, each of which about is 7 m long when fully deployed. Nickel-cadmium batteries can provide 1000 W of continuous power to the payload during eclipse phases.

Essential power for the thermal conditioning of certain subsystems and for limited operation of the payload during the periods when Eureca is in the Shuttle's cargo bay is provided by the Shuttle itself.

The data-handling subsystem provides for data to be sent to and from the carrier. Together with the telemetry and telecommand subsystem, it allows remote control and autonomous operation of the platform's subsystems and experiment instrumentation (S-band with a 2 kbit/s uplink, and a downlink dump rate of 256 kbit/s). When ground stations are out

Figure 1 — The Eureca mission profile

Figure 2 — Artist's impression of the Eureca carrier



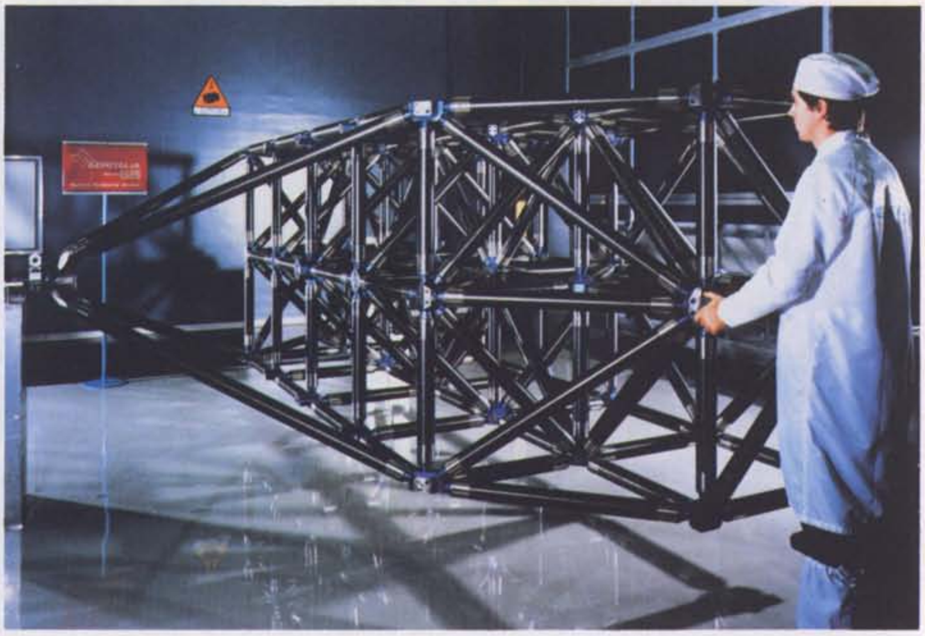


Figure 3 — Primary structure of the Eureca-A flight model

of sight, on-board recording of up to 128 Mbit is possible using an advanced magnetic bubble memory. Data flow to and from onboard equipment is controlled by Remote Acquisition Units (RAUs) via a serial data bus. Process Interface Adapters (PIAs) are used for 'intelligent' instruments, thereby ensuring well-known, standard interfaces.

Attitude determination, spacecraft orientation and stabilisation during all flight operations, as well as orbit-control manoeuvres, are performed by a modular Attitude and Orbit Control Subsystem (AOCS). This subsystem has its own computer and data bus. It has been designed for a maximum of autonomy and can be adapted to different mission modes by changing the onboard software. Additional attitude-control sensors and actuators can be connected directly to the AOCS bus without modifying the basic system architecture. Attitude control is achieved with reaction wheels and magnetic torquers, while slewing manoeuvres are performed with the reaction wheels only.

To reach its operational altitude and to return to its retrieval orbit, Eureca relies on an Orbital Transfer Assembly (OTA) based on a helium-pressurised hydrazine thruster system. Sufficient on-board consumables are carried for mission durations in excess of one year. The carrier's design also includes provision for in-orbit refuelling to allow still longer missions.

The various subsystems discussed above are accommodated within the Eureca structure itself. Payloads are to be accommodated on twelve 70 cm×70 cm support panels on top of the structure, giving a total area of about 5.9 m^2 for payload mounting. The full-scale mockup shown in Figure 4 illustrates the subsystem arrangements and solar-array geometry.

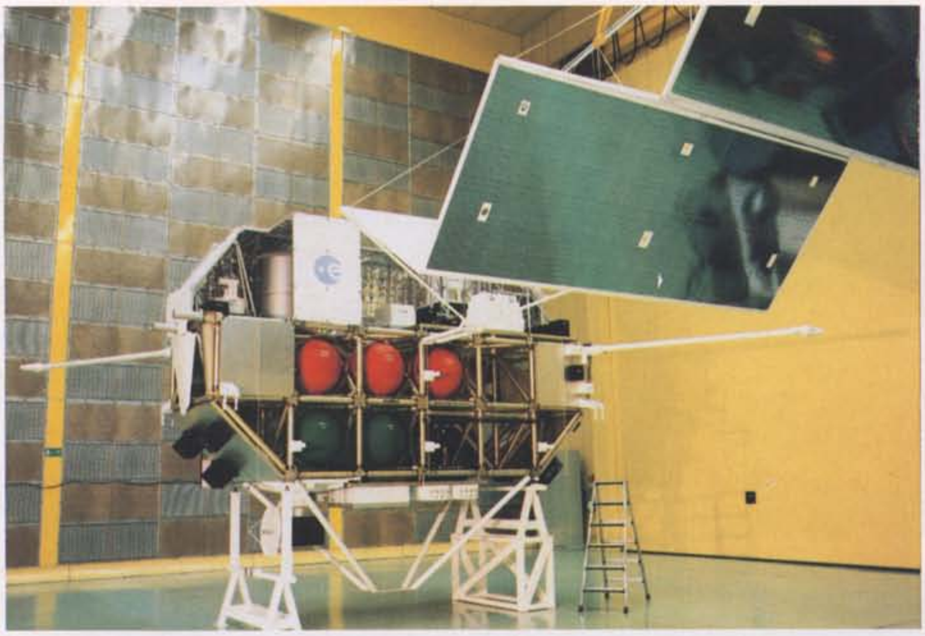
Major objectives of the Eureca Programme

- offer frequent flight opportunities at low cost
- meet known platform user requirements for microgravity, space science, Earth observation and technology
- establish a concept for retrievable, re-usable platforms that can be adapted to meet evolving mission requirements
- develop European capabilities in space-platform design, development, utilisation and operation
- develop an initial platform that meets the essential design, operational and programmatic requirements of future Space-Station elements

The first Eureca mission
The baseline Eureca carrier currently under development, called Eureca-A, is designed to provide a 10^{-5}g environment. It is therefore ideally suited for microgravity applications that require long-duration space exposure (e.g. certain crystal-growth experiments) and can be automated. The first mission falls into this category, and a further similar mission is in ESA's planning. It is still difficult to quantify absolute requirements for microgravity missions and today's activities are therefore essentially for research purposes, but commercial production might soon be forthcoming. The mission scenario under consideration assumes a total payload mass for each mission of 1000 kg, subdivided into 800 kg of facilities (ovens, biochambers, etc.) and 200 kg of materials.

A flight duration of six months has been assumed, with a turn-around time of 18 months or less on the ground between retrieval and the next launch.

Figure 4 — Mock-up of Eureca-A



Replacement of about 30% of the facilities after each flight has been assumed, to cope with wear-out and obsolescence.

Prior to the Shuttle tragedy, the first Eureca-A flight was scheduled for 1988, with launch early in the year and retrieval some six months later. The current Shuttle manifest indicates a possible launch in April 1991 and retrieval in the last quarter of 1991 (an earlier launch date is presently under discussion with NASA).

The first mission is devoted to the microgravity discipline, with experiments in both material and life sciences. Five facilities are being developed within the Eureca programme for this flight:
- an Automatic Mirror Furnace Facility (semiconductor growth)
- a Solution Growth of Organic Crystal Facility
- a Protein Crystallisation Facility
- a Multi-Furnace Assembly (processing of alloys and diffusion experiments)
- an Exobiological Radiation Assembly (exposure of biological material).

Thirty-seven experiments from eight Member States have been selected to exploit these facilities, from the 128 experiments originally proposed. Two 'add-on' microgravity facilities from Germany and from Italy will also be included:
- a High-Precision Thermostat
- a Surface-Forces Adhesion Facility.

Fifteen percent of the payload is reserved for space science (astronomy and solar physics) and technology experiments. Five science and three technology experiments compatible with the microgravity environment will therefore also be flown:
- Solar Spectrum Experiment
- Solar Variation Experiment
- Occultation Radiometer
- Wide-Angle Telescope (for X-rays)
- Timeband Capture Cell (to measure microparticles)
- Radio-Frequency Ionisation Thruster Assembly (RITA)
- Inter-Orbit Communication (IOC) Experiment
- Gallium Arsenide (GaAs) Solar-Cell Experiment.

The Inter-Orbit Communication technology experiment will evaluate the relay of data to the ground via the Olympus geostationary satellite, as a demonstration of high-speed, real-time data transfer for future Eureca flights.

Growth capabilities of Eureca

The present Eureca design and hardware are sufficiently flexible to allow increased performance without major re-design. The results of studies investigating the requirements for various mission applications have been taken into

The Eureca concept

- Relatively long duration flights (up to 6 or 8 months)
- High power and mass capability for the payload
- Retrieval of samples and equipment at the end of a mission, and hence re-use as required (up to five flights with the same hardware are foreseen)
- No disturbances from a crew during the flight, leading to long uninterrupted periods for microgravity experimentation
- Uncontaminated microgravity environment with continuous 10^{-5}g
- Manned attendance at launch (if desired) to ensure reliable setup and operation

account to facilitate future adaptation to other missions, such as technology, Earth-observation, solar-physics, and astronomy missions.

During the preparation of the Agency's Long-Term Programme it has became apparent that the scientific/application objectives of a substantial number of mission concepts can be achieved with relatively short but frequent flights on a Eureca-class carrier. More than 70 letters relating to space science, 48 to Earth-observation and 26 to technology demonstration, received in response to calls to propose experiments for Eureca, have confirmed the strong interest of the science and technology communities in securing frequent flight opportunities. Such expressions of scientific and technological user interest indicate that it will not be difficult to fill several Eureca platforms adapted to these types of experiments.

In view of the potential European involvement in Space-Station activities, the Eureca utilisation programme can be expected to evolve into a very cost effective tool for providing critical experience relevant to the utilisation of the Space Station and its co-orbiting platforms/elements. This aspect has been recognised by the potential participants (Member States) in the Columbus Programme, which considers an enhanced Eureca — called 'Eureca-B' — to be a fundamental element of that Programme.

This Eureca-B platform is foreseen as a three-axis-stabilised, retrievable carrier with orbital transfer capabilities, designed for autonomous operation. It would employ passive thermal control techniques only, rather than the active cooling system used on Eureca-A. This will call for multi-layer insulation blankets and electrical resistance heaters for temperature control of Eureca-B's subsystems and payload (Table 1). Eureca-B would provide full support to its payload throughout the carrier's

Table 1 — Technical system characteristics envisaged for Eureca-A and Eureca-B

	Eureca-A	Eureca-B
Payload mounting area	1.5×4 m^2	1.5×4 m^2
Payload mounting volume	8.5 m^3	8.5 m^3
Total system mass	4200 kg	4200 kg
— Payload mass	1000 kg	1000 kg
	(depending on mission duration, mission profile, and mission-specific subsystem equipment)	
Total electrical power	5 kW	5 kW
— Continuous payload power	1 kW	1 kW
— Peak payload power	1.5 kW	1.5 kW
Thermal control	Liquid-loop and multi-layer insulation	Passive with multilayer insulation
Data management		
— Bus data rate to payload	1.5 kbit/s	100 kbit/s
— Data storage for payload	128 Mbit	To be enlarged
Data transmission to ground		
— Via S-band	256 kbit/s	256 kbit/s
— Via K/A-band	—	Planned via IOC
Orbit and attitude control		
— Altitude change capability	350 m/sec	350 m/sec
— Pointing direction	To Sun	Celestial
— Pointing accuracy	$\pm 1°$	± 1 arcmin
— Stability	$\pm 0.5°$/h	± 1 arcmin/h
— Reconstitution	$\pm 0.5°$	± 5 arcsec
— Slewing capability	Not applicable	3°/min
Operational orbit	Circular, initial altitude 525 km, 28° inclination	Circular, mission-dependent, 28° inclination
Deployment/retrieval orbit	296/315 km	296/315 km or 500/500 km (Space-Station orbit)
Microgravity constraint	$\leq 10^{-5}$g at 1 Hz $\leq 10^{-3}$g at 100 Hz	Not applicable
Mission duration	6 months operation 3 months retrieval	More than 1 year operational
Design life	5 missions or 10 years	5 missions or 10 years
Turnaround time	<1.5 years between missions	<1.5 years between missions
Turnaround mode	Payload exchange on ground	Payload exchange on ground with growth to in-orbit servicing

operational period, which may last up to two years before retrieval.

Potential roles for Eureca-B

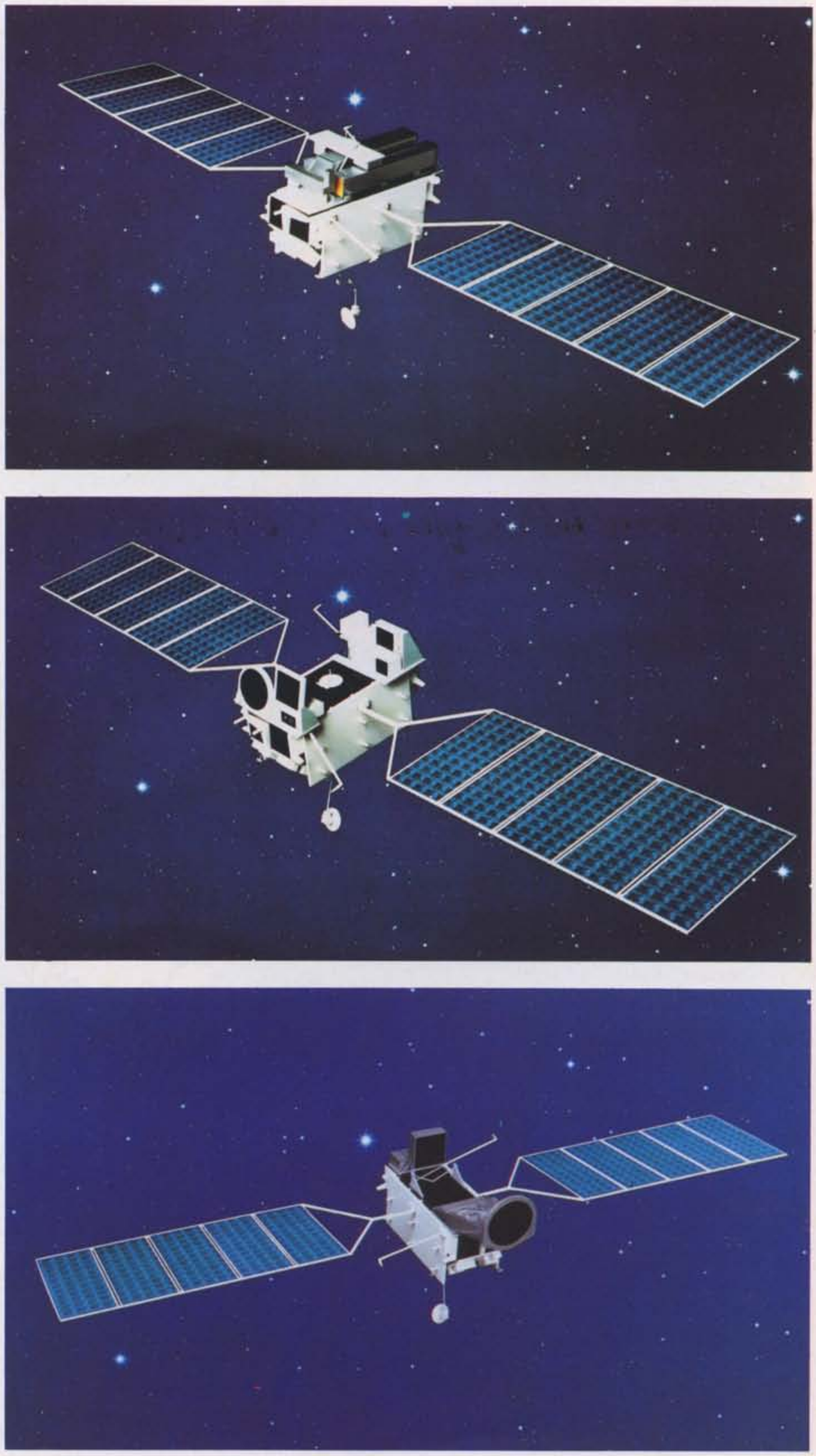
To promote the use of Eureca, over the last two years ESA has conducted several payload-accommodation and operation-enhancement studies. These were supported particularly by the Agency's Space Science and Microgravity Directorates. The main results of these studies have confirmed that the baseline Eureca-A, with some minor adaptation, would be a useful tool for achieving a number of long-term programme objectives in space science. In addition, it will allow ESA and NASA to demonstrate advanced operational concepts for in-orbit refuelling, payload exchange, and close-proximity operations.

The Sophya-Gretel-Grasp scientific missions

Studies have been performed to establish the feasibility of installing three specific types of payload on board Eureca, and to identify any modifications to the carrier needed to fulfil their mission and operational requirements. The model payloads for 'Sophya' and 'Gretel' were defined by ESA/ESTEC to address the solar-physics and astronomy disciplines, respectively. The 'Grasp' mission, submitted to ESA in response to a Call for Mission Proposals, addresses spectroscopy and positioning of celestial gamma-ray sources (astrophysics discipline). Figure 5 shows the three Eureca payload-accommodation configurations studied so far in relation to these missions.

The studies would seem to indicate that the Eureca system is able to fulfil the Sophya, Gretel and Grasp mission requirements. The baseline design, however, will need adaptation by the addition of appropriate items of equipment (data-handling and attitude control) and relatively small modifications to some of Eureca's subsystems.

Figure 5 — Possible Eureca payload configurations for the Sophya, Gretel and Grasp missions



Eureca-B's mission lifetime of up to a maximum of two years is considered adequate to provide a rich scientific programme and a full return on investment to the participating institutes.

Servicing demonstration mission

In parallel with the above scientific-payload accommodation studies, a study was made to assess the enhancement of the baseline Eureca-A mission capabilities. The prime objectives of this study were to analyse improvements that could stem from enhanced in-orbit capabilities, to define the necessary servicing functions, and to design the requisite hardware and software.

Concepts to demonstrate equipment exchange and refuelling in orbit, as well as subsystem changes to improve the carrier's power-generation and orbit-manoeuvring capabilities, are summarised in Figure 6.

From these studies, it was concluded that the enhanced carrier Eureca-B should provide the following upgraded capabilities:

- Increased mission duration up to a maximum of two years.
- Celestial pointing by improved manoeuvring, with implementation of a bearing and power-transfer assembly (BAPTA) for solar arrays, etc.
- Improved data rates for data acquisition, storage on high-data-rate recorders, and transmission via an operational inter-orbit communication system with increased ground contact times.
- Passive thermal-control concept for longer missions by deletion of liquid-loop system.
- Increased electrical power generation by means of two additional solar panels for highly inclined orbits with reduced solar aspect angles, with the BAPTA for solar-array rotation, and improved power storage with two additional batteries.
- Improved manoeuvring capabilities for proximity operations in the vicinity of the Space Shuttle and the Space Station, with the additional goal of being able to reach the pick-up zone for Shuttle retrieval within 48 h of beginning descent manoeuvres and to maintain retrieval-ready conditions for longer periods by means of active station-keeping. An approach-to-Space-Station thrust capability of 20 N, supported by an improved

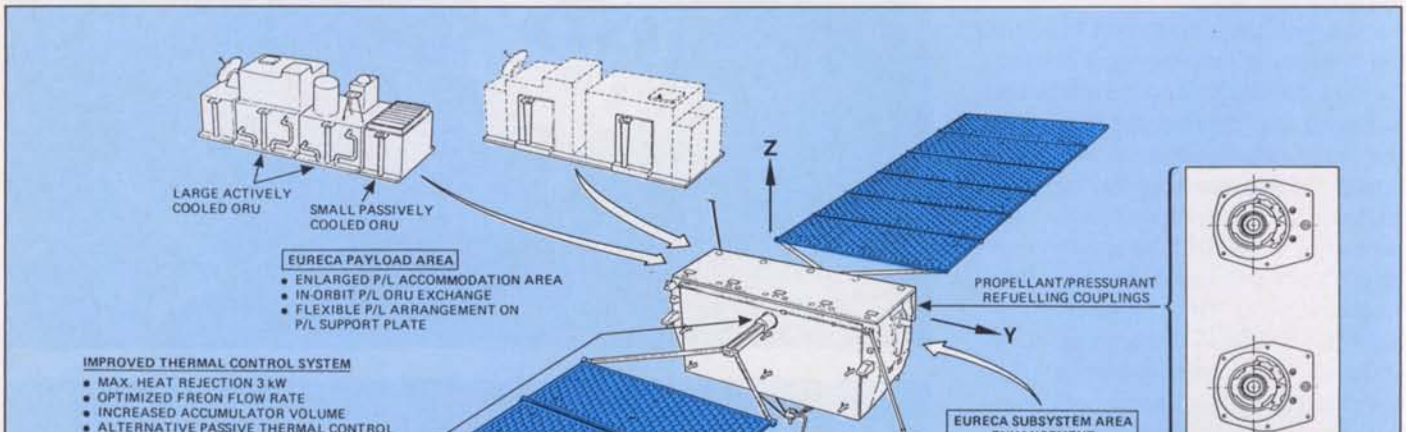


Figure 6 — The Eureca-B mission-enhancement concept

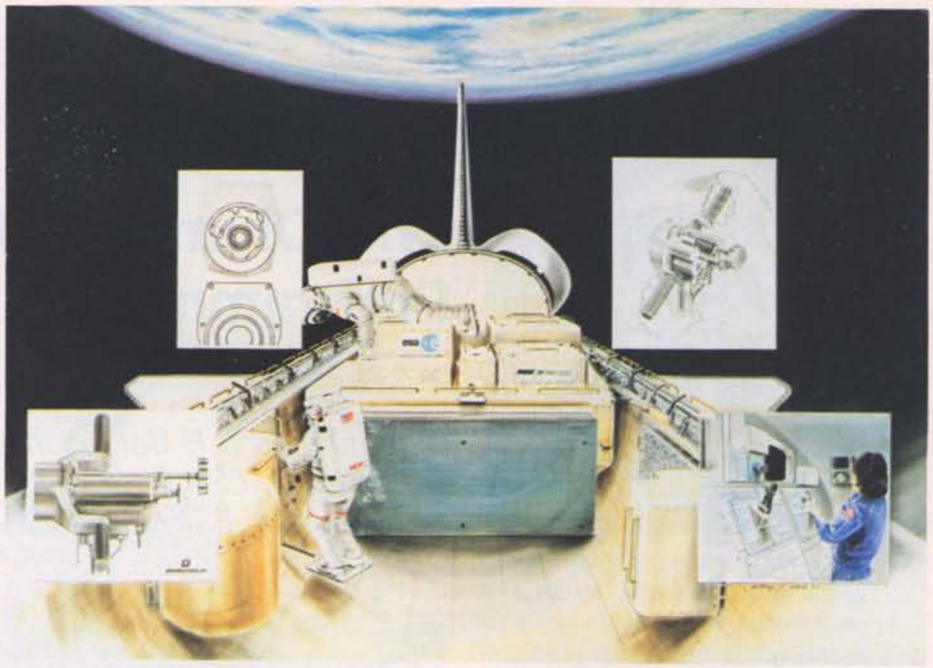


Figure 7 — Artist's impression of a Eureca carrier being serviced aboard the Space Shuttle

Figure 8 — Artist's impression of Eureca servicing by Hermes

propulsion/actuator system, should also be pursued.
- Improved payload integration by reducing the number of standard platform-to-payload interfaces.

These operational concepts can be realised within the payload transportation and servicing capabilities of the Shuttle Orbiter, as illustrated in Figure 7. Future alternatives to the Shuttle are, however, under investigation, including an independent European platform scenario for transportation and servicing. These include:
- a Eureca servicing mission
- Eureca transportation by Ariane
- Eureca payload and subsystem servicing by Hermes (Fig. 8)
- Eureca retrieval by Hermes
- Eureca servicing at the Space Station.

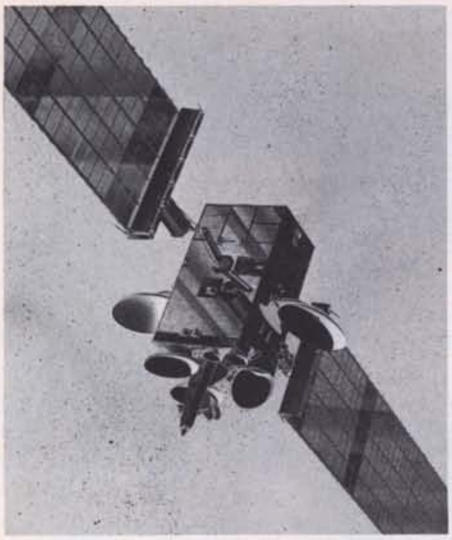
Conclusion

The Eureca-A and -B platforms are particularly well-suited to bridging the gap between now and when the Space Station becomes fully operational in the mid-1990s. Their development will not lead to an overlap or a duplication in the fields of microgravity, Earth observation, space science or technology demonstration, but will rather complement those programmes by providing a unique and cost-effective infrastructure for performing missions that would otherwise not be possible.

From a scientific viewpoint, the Eureca-A/B concept can accommodate an important class of experiments that complement the major programme elements of the respective user programmes. In Earth observation, for instance, it provides a unique testbed for instrument development and science-oriented studies not at present covered by the immediate needs of 'application driver' interests.

It is also recognised that Eureca-A and -B can provide experience in design and operational technologies required for embarking on more complex platforms at a later date. In particular, technologies and operational capabilities such as re-fuelling, in-orbit exchange of Orbit Replaceable Units (ORUs), proximity operations with a manned vehicle, and rendezvous and docking operations can be demonstrated cost-effectively during Eureca missions.

By the end of this decade, Eureca-A, designed primarily for microgravity research, will be a proven operational system. Assuming Eureca-B is given the go-ahead in 1987, its first mission, dedicated to space science and applications, could take place in the 1991—1992 period. The Eureca-A and -B platforms would then together be ideally suited to providing a series of flight opportunities for scientific, technological and other potential users of the Space Station. Such opportunities could be used expressly to gain experience in Space-Station operating concepts, becoming increasingly representative of the forseen operating modes for Columbus. This type of scenario is seen both by the Agency and potential user communities as an essential element in preparing for the cost-effective exploitation of the Space Station.



The Olympus Utilisation Programme

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Olympus is a large communications satellite currently being constructed for ESA by European industry. The first flight model, Olympus-1, will be placed in geostationary orbit (at 19°W) by an Ariane-3 vehicle in 1988. It will carry a multipurpose experimental payload to test future telecommunications flight hardware and provide the opportunity for communications and broadcasting experiments in both Europe and Canada. The experience gained will be used to design operational satellite telecommunications systems for the nineties.

The ESA programme for the development, construction, launching and operation of Olympus is funded by the Governments of the United Kingdom, Spain, The Netherlands, Italy, Denmark, Canada, Belgium and Austria.

There are four quite separate payloads on Olympus-1 (Fig. 1), each with its own antenna:
- the Direct Broadcast Service (DBS) Payload
- the Specialised Services Payload
- the 30/20 GHz Advanced Communications Payload
- the Propagation Payload.

The exploitation of these payloads in orbit will be co-ordinated under an overall Olympus Utilisation Programme, which will encompass all aspects of the satellite's use.

Direct-Broadcast Service

Payload configuration

The 3 dB and 9 dB coverage contours for the direct-broadcast payload are shown in Figure 2. The uplink is in the 18 GHz frequency band and the downlink at 12 GHz. There are two channels corresponding in frequency to numbers 20 (or 28 by switching) and 24 of the WARC 77 Frequency Plan. The high-power amplifiers are duplicated to provide full redundancy on both channels.

The coverages of the two beams are shown for the nominal configuration of the antennas, which provides an elliptical beam over Italy and a circular beam over central Europe. Both beams are, however, steerable over a very wide range, which will allow Olympus to be used in other countries in Europe, Scandinavia and North Africa.

The uplink coverage is provided by a wide-beam antenna on the spacecraft, permitting the DBS channels to be accessed from anywhere in Europe.

Planned use of capacity

Table 1 shows the presently scheduled usage for the DBS payload. The two main users, with whom agreements have already been signed, will be the RAI (Italian Broadcasting Organisation) and the EBU (European Broadcasting Union).

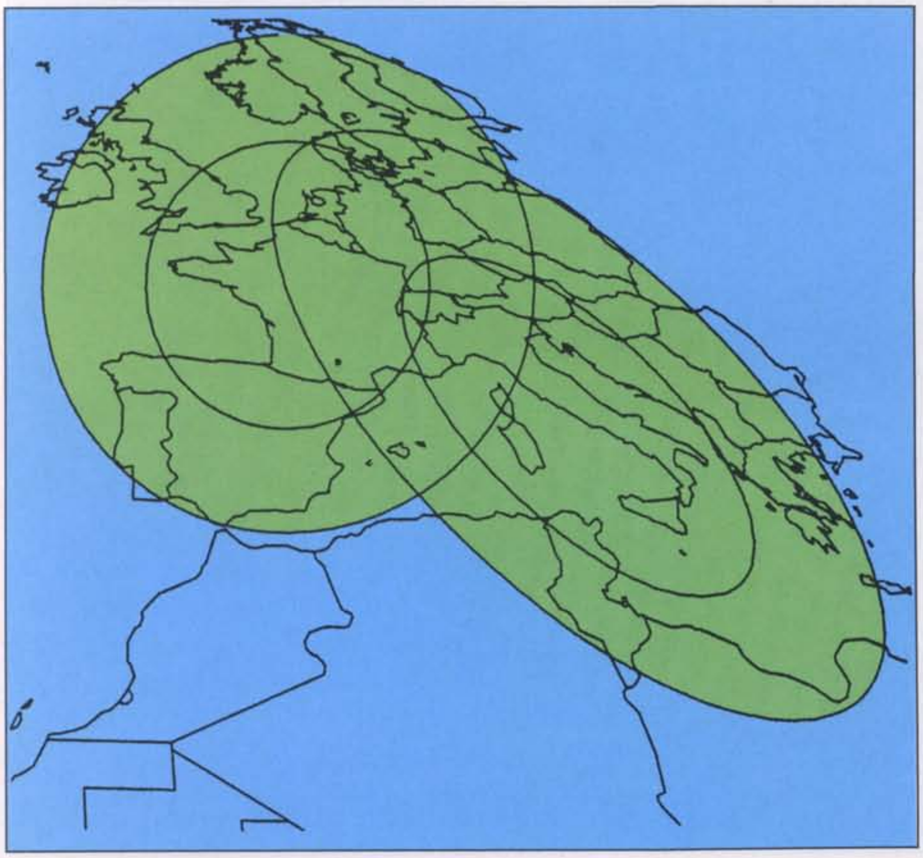
The RAI channel will provide DBS television to Italy in particular, but also to quite a wide outer area at slightly reduced power levels. The capacity available to the EBU will be taken up by the broadcasting organisations who are EBU members.

The signals to be transmitted will be of the 'MAC Packet' family, with a nominal bandwidth of 27 MHz. The satellite radiated power (EIRP) is 62.5 dBW at beam centre, which will allow earth stations of 45 cm diameter to be used within the inner contour of Figure 2, and 90 cm diameter within the outer contour.

There are many other potential users of the broadcast transponders, as Table 1 shows. In particular, education and training applications have been found in many fields. These include educational services such as the Open University in England, language broadcasts to closed user groups, and training by companies for their customers, employees or suppliers. All of these activities will be fitted around the core activities of RAI and EBU television in constructing the operating schedule.

Figure 1 — The thermal model of the Olympus spacecraft being readied for testing at British Aerospace

Figure 2 — Coverage of the Olympus Direct Broadcast Service (DBS) Payload



Earth-segment hardware

ESA is procuring a 4 m diameter transportable earth station, called Test and Demonstration Station No. 5 (TDS-5) from Selenia Spazio, which can be used to send television signals to either of the Olympus repeaters. The station (Fig. 3) will be available, on a loan basis, to broadcasters who wish to run a pilot experiment to assess the possibilities of direct television broadcasting in their region.

The uplink station for the RAI channel will be built by Telespazio and located at Fucino, near Rome.

A typical receive installation for DBS will consist of an outdoor unit composed of the antenna and low-noise down-converter, and an indoor unit which will be connected to the television receiver (Fig. 4).

Specialised Services

Payload configuration

The coverage of the Specialised Services Payload is shown in Figure 5. There are four channels, each of which has a nominal bandwidth of 18 MHz. Two of the channels can be switched to a bandwidth of 36 MHz when necessary. Four of the five possible uplink signals, corresponding to the five separate beams, to the repeater system are interconnected to four of the five downlink beams by an on-board four-by-four switching matrix, which can be operated in either a static or dynamic mode. The dynamic mode enables experiments with satellite-switched TDMA to be undertaken. The reflector of the satellite antenna is mechanically steerable. The whole five-beam pattern can therefore be slewed over a very wide geographical area.

The uplink frequency for the payload has two possible bands: 13.0 to 13.25 GHz and 14 to 14.3 GHz. The downlink frequency bands are in the range 12.5 to 12.75 GHz.

Table 1 — Summary of DBS payload participation

Type of experiment	Organisations involved	Remarks
Pre-operational Direct Broadcast Satellite (DBS) television	The Italian broadcasting organisation RAI will have one DBS channel on Olympus. The other channel will be used by the European Broadcasting Union (EBU).	ESA has signed agreements with RAI and the EBU to make the Olympus TV channels available.
Interactive information services	The Dutch publishers VNU and Delft University will conduct an audiographic experiment. The British Broadcasting Corporation has proposed a data-casting experiment, and British Telecom International also.	These services will be carried within the MAC Packet standard.
Educational and training experiments via DBS television	Sixteen universities, educational establishments and companies throughout Europe have made proposals to ESA for Olympus time.	Applications include remote learning for many subjects, ranging from languages to medicine. Corporate training is also an area of high interest.
Sound broadcasting	New Media Services BV.	Proposal to broadcast high-quality digital sound programmes in parallel with DBS television.
Technical tests	Technical universities, industry and research laboratories.	Tests include: — Antenna measurement techniques — High-definition TV — Comparison of different TV standards.

Table 2 — Summary of Specialised Services payload participation

Type of experiment	Organisation	Remarks
SS-TDMA	BTI/Danish PTT, British Telecom International	Specific plans not yet available. An initial agreement exists
SS-TDMA	CNUCE, Univ. Graz	Detailed experiment programme description received
Tele-education	Plymouth Polytechnic	ESA will lend a TDS-4 station to Plymouth Polytechnic for this experiment
TV distribution to 1 m dia. antennas	Various broadcasters	
Educational network	University of Surrey and Ecole Nationale Supérieure de Télécommunications plus ten other potential participants	Requires small earth stations. Could employ TDMA at a later stage.
Network of very small earth stations in Africa	ESA and the European Commission	This experiment involves swinging the Specialised Services antennas towards Africa for a certain part of the day
Very small earth station experiment	AT&T/Philips	The trial will be for business communications at 64 kbit/s
Image file transfer related to Apollo document transfer project	Netherlands Space Research Laboratory (NLR)	Document distribution with improved techniques for error control and fade compensation
Educational links using compressed video	British Columbia Institute of Technology	Co-operation with Ayr College in Scotland is envisaged
News-gathering experiment	Independent Television	Details not yet available
Frequency diversity	Politecnico di Milano	This experiment will employ the Specialised Services and the 30/20 GHz transponders
Technical tests	Leeds University Ministry of PTT in Italy CSELT	These experiments include antenna measurement, clock-synchronisation techniques and coding techniques

Figure 3 — The TDS-5 earth station

Transmit frequency band	: 17.3 — 18.1 GHz
Receive frequency band	: 11.7 — 12.5 GHz
Maximum EIRP	: 82 dBW
Antenna diameter	: 4 m
Transmit power	: 500 W
G/T	: 24 dB (1/K)
Number of selectable channels	: 40
Polarisation	: Circular, RH and LH

The peak radiated power of each of the beams is 54 dBW. If we assume that users work within the 3 dB contours of the beams and that any proposed system will require at least 12 dB carrier-to-noise ratio for the full bandwidth of 18 MHz and 36 MHz, respectively, the earth-station antennas have to be of the order of 1 m in diameter for the 18 MHz case and 1.5 m in diameter for the 36 MHz case. The coverage contours out to 4 dB are shown in Figure 5 with the antenna reflector in its nominal position.

Planned use of capacity

There are many possible applications for this payload. These include satellite-switched TDMA (SS-TDMA), video-conferencing using 2 Mbit/s carriers, and television distribution.

The main interest in this payload at present is coming from the scientific community. The Technical University of Graz (Austria), CNUCE (Italy) and RAL (United Kingdom) have proposed an SS-TDMA experiment with a maximum bit rate of 8 Mbit/s. British Telecom and the Danish PTT are also planning to conduct an SS-TDMA experiment.

There is also interest in the use of the payload for educational television distribution, particularly from Plymouth Polytechnic in the UK. One of the Agency's stations will be used for an uplink in this context.

An outline of the present plans is given in Table 2.

Earth-segment hardware

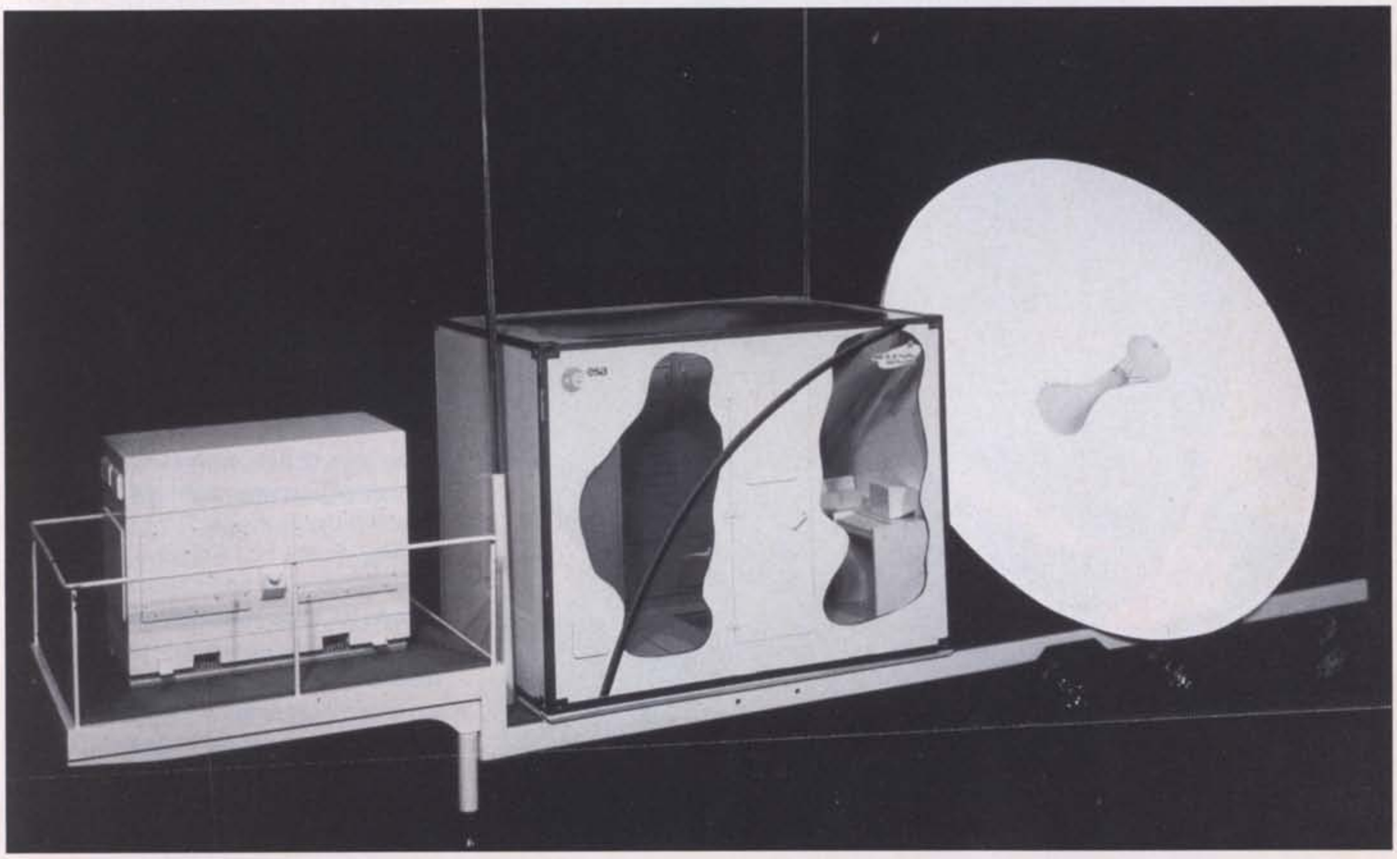
ESA's plans for this payload include the provision of two transportable earth stations, called 'TDS-4's', which can be used to access the payload from anywhere inside the coverage area. These stations, which are being manufactured by British Aerospace, will have antenna diameters of 3.5 m (Fig. 6).

Advanced Communications

Payload configuration

The coverage of this payload is shown in Figure 7. The payload 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 wideband capability, which has been included for certain specialised experiments. This has a bandwidth of 700 MHz. There are two spot beams, each having a 1° beamwidth to the 3 dB contour. Both beams can be steered independently over a very wide coverage range by means of mechanical steering mechanisms.

There are three output amplifiers, each of 30 W, arranged in a one-for-two redundancy configuration. The radiated power at beam centre is approximately



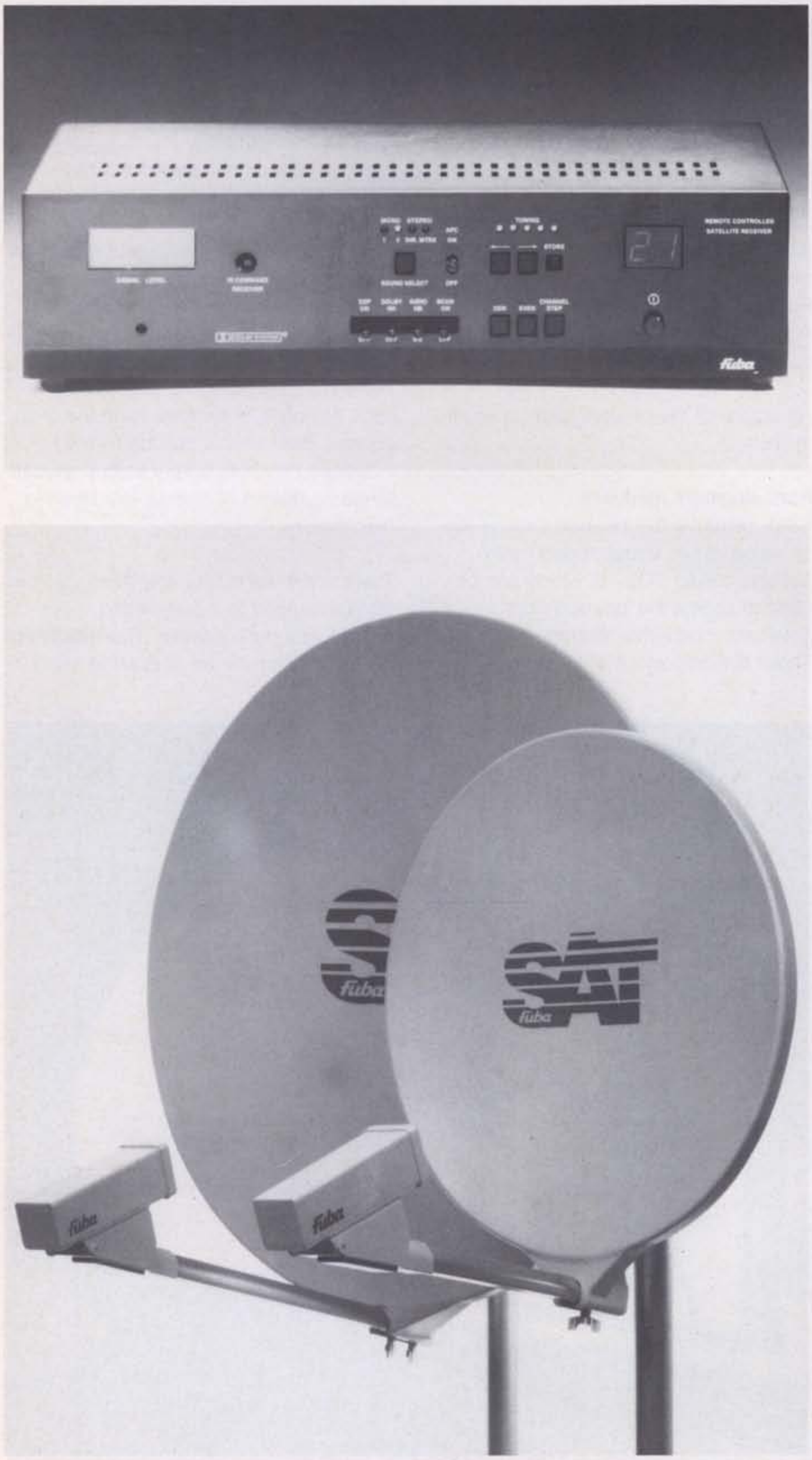


Figure 4 — Typical Direct Broadcast Service (DBS) receiver equipment for domestic use

54 dBW, which permits the use of small-diameter earth stations for most applications.

Planned use of capacity

A great deal of interest has been expressed in the use of this payload and its schedule is therefore quite crowded. The main potential users are listed in Table 3.

Many of the experimental applications are in the area of business communications using small earth stations. The Canadian Communications Research Centre (CRC) will set up an experimental network of stations for business communications. It will also experiment with potential onboard processing systems using double-hop techniques and equipment on the ground to simulate a future satellite processor.

British Aerospace and ESA will execute a business communications experiment in the United Kingdom which will involve data, voice and simultaneous-presence video conferencing. The Agency's TDS-6 earth stations will be employed initially for this experiment at three United Kingdom locations.

Telespazio, in collaboration with the Politecnico di Milano and other Italian technical organisations, has also announced its intention to carry out business-communications and teleconferencing experiments.

In the area of data transmission, a number of European scientific institutes including the Technical University of Graz (Austria), Rutherford Appleton Laboratories (UK) and CNUCE (Italy), will operate an experiment that will link together computer networks in the various countries. It will demonstrate advanced high-speed data networking techniques that will subsequently be applied in future operational systems. A further data experiment called 'CODE' (Co-operative Olympus Data Experiment)

Figure 5 — Coverage of the Olympus Specialised Services Payload

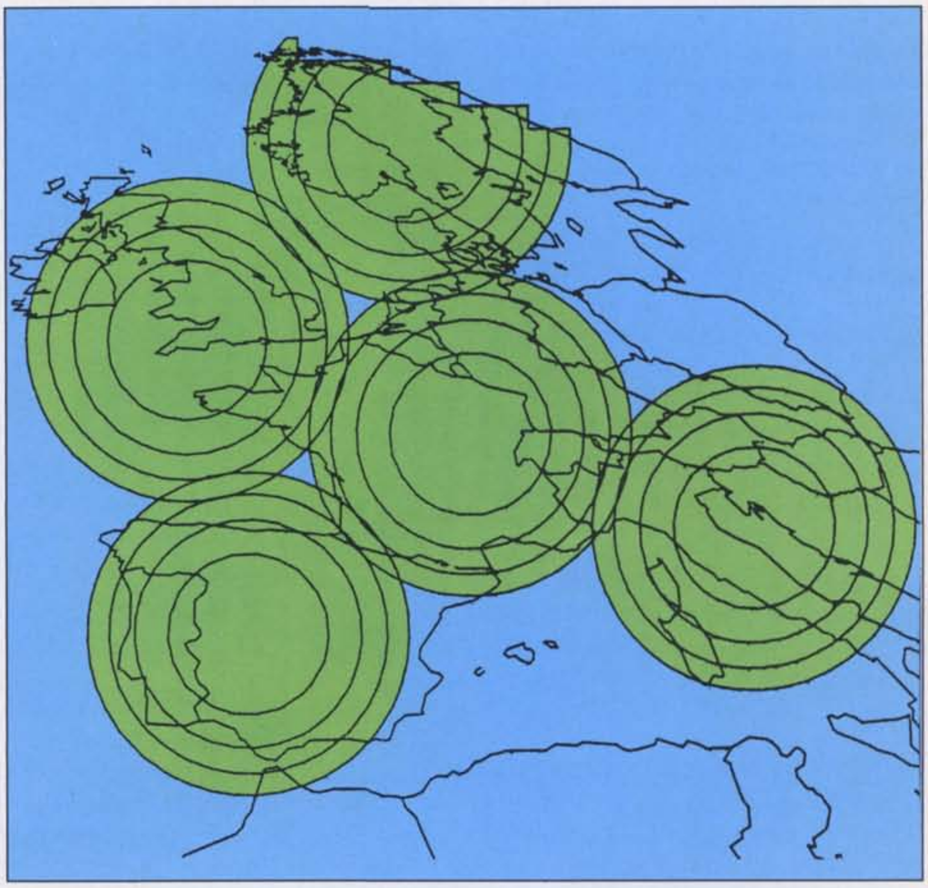


Figure 6 — The TDS-4 earth station

Transmit frequency band	: 13 — 13.25 GHz 14 — 14.3 GHz
Receive frequency band	: 12.5 — 12.75 GHz
Maximum EIRP	: 73 dBW
Antenna diameter	: 3.5 m
Transmit power	: 2 x 250 W
G/T	: 25.5 dB (1/K)
Polarisation	: Linear

has been devised by a subgroup of the Earth Station Working Group (see below), consisting of representatives from both universities and scientific establishments. This experiment will involve linking together scientific and educational establishments using very small aperture terminals throughout Europe.

ESA will use the 30/20 GHz payload of Olympus for data-relay experiments to and from the Eureca orbiting scientific platform scheduled for launch in 1990 (see article elsewhere in this issue). This low-orbit vehicle will carry an Inter-Orbit Communications Module that will send signals to and receive signals from the Olympus transponders.

Eureca will be tracked by the steerable antennas of Olympus and the data originating from the platform will be transmitted and received by an ESA earth station at a fixed location in Europe.

In the broadcasting field, it is planned to demonstrate the capability of Olympus to relay high-quality television pictures and sound from remote parts of the world to European locations. In particular, using the Agency's air-transportable earth stations, it will be possible to relay items of topical interest using the steerable spot beams of the 30/20 GHz payload from, for example, South America to a station in Europe. From there, the DBS payload of Olympus can be employed to distribute the television event on a European or even wider scale.

The EBU has also expressed interest in conducting high-definition television experiments using the 30/20 GHz Olympus payload.

The wideband capability of the payload will be used by scientific experimenters to make measurements of phase correlation in very wide band transmissions at millimetre-wave frequencies. There will also be a number of scientific experiments that will address the subject of fade countermeasures.

Table 3 — Summary of 30/20 GHz Advanced Communications payload participaton

Type of experiment	Organisation	Remarks
Data relay	ESA	In-Orbit Communications Module (IOC) fitted to the Eureca platform
Business network	Communications Research Centre, Canada	Business communications between very small earth stations
On-board processing	CRC Canada	Performed using a double hop and equipment on the ground to simulate an active satellite
Inter-networking experiments	Graz/CNUCE/Rutherford/FUB/CSATA/ Univ. di Firenze	Full description received
Correlative phase modulation N × 64 kbit/s	Philips/Eindhoven University/AT&T	Experiment is centred around a 1—2 m diameter earth station being developed by AT&T/Philips
High-definition television	EBU	Experiments and demonstrations to determine availability and system quality. High-definition television will also be demonstrated
Business network	BAe & ESA	TDS-6 stations will be used at three locations in the UK. Fade countermeasures will also be involved
Wideband correlation experiment	Rutherford Appleton Laboratory (UK)	Analysis of high-speed pseudo-random sequences to find differential path delay
Frequency-diversity experiment	Politecnico di Milano	Use of Ku band capacity to alleviate fades at Ka band
Point-to-multipoint	University of Surrey	A cooperative experiment involving several universities and technical laboratories
International broadband communications	ESA	ESA participation in the CEC's RACE Programme could generate an Olympus requirement
Video-conference multipoint	TSPT/Fondazione Ugo Bordoni	
Tele-education	FUB/various Italian institutes	Two or three 1.2 m diameter stations will be used, each with receive and low-power transmit capability
Small-scale diversity	FUB/CSTS	Part of overall Italian experimental plan
Digital TV	FUB/RAI	Investigation of possible new broadcasting bands
Fade countermeasure tests	BTI/Univ. of Surrey/Istituto Superiore/Swedish PTT/Portsmouth Polytechnic	Several fade countermeasure techniques will be explored by the various organisations
Digital TV	Inmarsat/Marconi	Live TV to ships as a possible future Ka-band system
Telecommunications to aircraft	Marconi	Further details to be defined
ISDN tests	Danish PTT/Swedish PTT	Performance evaluation during fade events
Adaptive channel coding	Swedish PTT	
Point-to-point and multipoint video-conferencing	FUB in Italy	Preparing possible new systems
Remote news gathering	ITN/Marconi/EBU	Uses the steerable capability of the Olympus antennas

Figure 7 — Coverage of the Olympus 30/20 GHz Advanced Communications Payload

These include experiments with diversity, both in frequency and space, and with digital techniques to alleviate the effects of fading. Most of the more general experiments — for example the British Aerospace video-conferencing experiment — will investigate fade countermeasures as a necessary element of communications at 30/20 GHz.

Earth-segment hardware
Earth stations are being built in Canada, the United Kingdom, Italy, Austria and The Netherlands for the various experiments. There are approximately twelve stations of the 2 or 3 m diameter transmit/receive class, plus numerous smaller stations for thin-route transmit/receive and receive-only applications.

The Agency is procuring three stations — TDS-6 A, B and C — which will be land-, sea- and air-transportable. These stations (Fig. 8), which are being built by Marconi in the United Kingdom, will be used initially in the BAe business-communications experiment, but they will also be employed for the Eureca experiment and for outside-broadcast experiments on a time-shared basis.

Two further 30/20 GHz earth stations, called 'TDS-7's', are being built for the Agency and Telespazio, respectively, by Selenia Spazio. These stations are similar in specification to TDS-6, but will employ lower power transmit amplifiers. They will have lower radiated power, but will consume less primary power and be more portable.

Propagation

The propagation payload
This payload provides three beacon signals at frequencies of approximately 12, 20 and 30 GHz, called B_0, B_1 and B_2, respectively. The beacons are all linearly polarised and mutually aligned in polarisation. The B_1 (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 B_0 (12 GHz) beacon has a global coverage with a minimum radiated power within coverage of 10 dBW. The B_1 and B_2 beacons have European coverage and a minimum radiated power of 24 dBW. 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 amplifiers are also fully backed up by redundant equipment.

Planned experiments
A great deal of interest has been shown by many scientific and technical establishments in collecting propagation data using the Olympus beacons (Table 4). The beacon signals provide the possibility not only to make absolute measurements of attenuation and cross-polar effects at 20 and 30 GHz, but also to make direct and simultaneous comparison between 12, 20 and 30 GHz phenomena. This is very valuable feature, because it will allow the considerable amounts of 12 GHz data already available for many locations to be scaled to the higher frequencies.

Earth-segment hardware
As part of the co-ordination activities proceeding under the auspices of the Olympus Propagation Experimenters Group (OPEX), a great deal of thought has been given to the design of suitable beacon receivers. This has resulted in a 'Handbook for Beacon Receiver Design', which has been endorsed by the group as a whole and widely distributed.

Most of the scientific establishments involved will at least partially construct their own receiving stations. Various industrial companies have, however, designed Olympus beacon reception stations that can be purchased as a complete unit or in component form, according to the wishes and resources of the experimenter concerned.

Co-ordination aspects
Use of the Olympus payload will be scheduled and coordinated by ESA. To this end, a Utilisation Board has been established to deal with applications for experiments and demonstrations. The Board is currently preparing an outline plan for the first year of Olympus

operation and this will shortly be submitted to the Agency's Delegations for approval.

ESA has invited official applications for use of Olympus and a total of eighty-one organisations have applied at a preliminary level. Further discussion and clarification continues in order to refine and finalise these proposals.

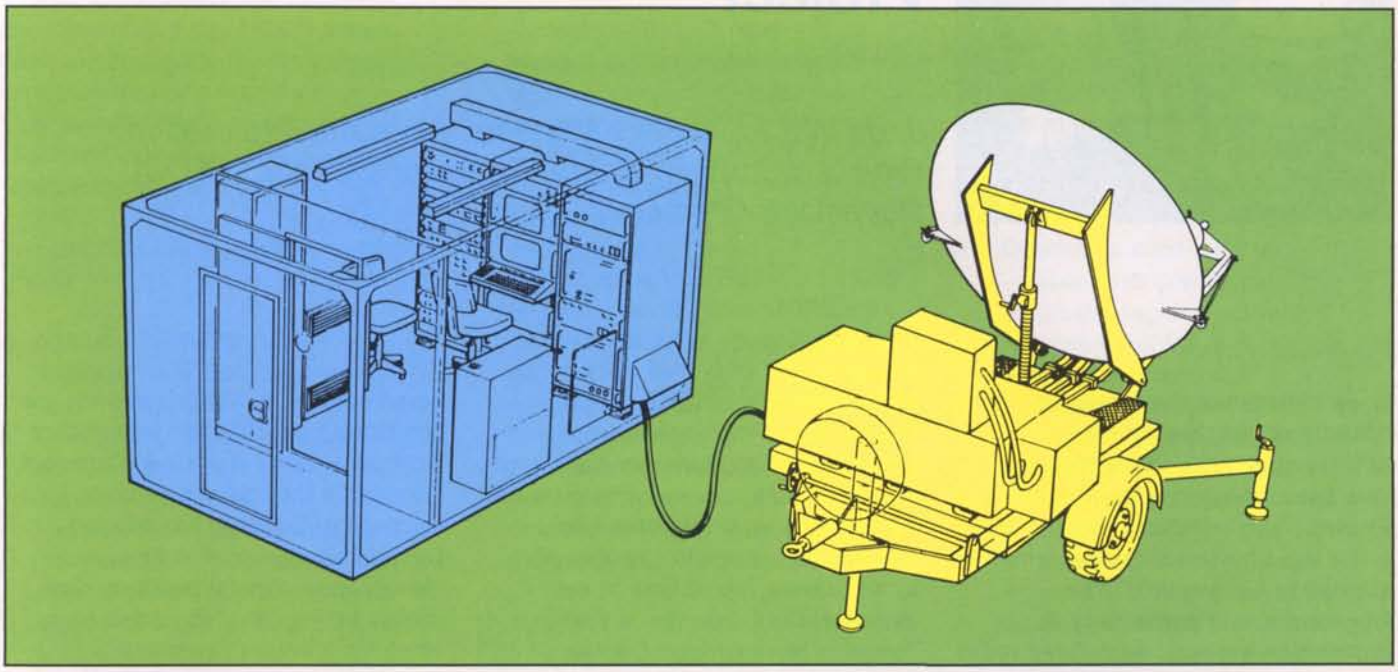
For satellite experiments that are related to international public telecommunications in Europe, a consultative agreement has been signed with Eutelsat which will enable the interests of that organisation to be safeguarded, whilst at the same time encouraging submission of proposals for Olympus use from Eutelsat on behalf of its member organisations. Eutelsat have set up a committee (Groupe des Expérimentateurs CEPT pour Olympus, or GECO) which will coordinate their inputs before passing

Table 4 — Summary of Propagation Payload participation

Organisation	Location	Remarks
British Telecom	Martlesham, UK	Will receive all three beacons. 6 m dia. station for 20/30 GHz and 1.8 dia. for 12 GHz
CNET	Gometz, France	Adaption of previous OTS/Sirio station
CNET/CRPE	Bretagne, France	Two small stations
CSTS	Italy	Three stations in various parts of Italy
FUB	Italy	25 small stations for attenuation measurements. Some with cross-polarisation measurement capability
ETSI	Barcelona, Spain	Two stations. One each for 12.5 and 20 GHz, respectively
FTZ	Darmstadt, Germany	Station will receive all three frequencies coherently
DFVLR	Cologne, Germany	Tentative plans for a full receive capability
Cork and Dublin Universities	Ireland	Plans for a station in Ireland
Finnish PTT	Helsinki	Plans for PTT/University co-operation
Technical University	Eindhoven, Netherlands	A full three-frequency station will be built, 4—5 m dia. antenna
Netherlands PTT	Netherlands	Three earth stations. Conversion of existing 10 m station at Nederhorst plus stations at Delft and Leidschendam (The Hague)
Lancaster Polytechnic	Coventry, UK	Beacon measuring station for 12.5 and 30 GHz, plus a 30 GHz radiometer
Danish/Swedish PTT	Denmark	Cooperative project for participation with two small stations. Radiometers already exist
Technical Univ. Graz	Austria	No firm plans exist, but participation is being considered
University of Louvain	Belgium	Plans for a station in Belgium, supported by the Belgian Government
BAe	Stevenage, UK	Prototype station for demonstration exists. Plans for propagation measurements
RAL	Chilton, UK	Tentative plans for reception at 20/30 GHz
Other universities	UK	Execution of plans dependent on funding
Telecom Research Establishment	Kjeller, Norway	Station with full receive capability under development

Figure 8 — The TDS-6 earth station

Transmit frequency band	: 28 — 28.7 GHz
Receive frequency band	: 18.85 — 19.55 GHz
Maximum EIRP	: 77 dBW
Antenna diameter	: 2.5 m
Transmit power	: 2 x 350 W
G/T	: 25.5 dB (1/K)
Polarisation	: Linear



them to the Agency for discussion and approval. An Agency representative has been invited to attend GECO meetings.

In the area of 30/20 GHz communications, an ad-hoc group chaired by Prof. Carassa of Politecnico di Milano has made considerable progress in stimulating interest in the use of Olympus and encouraging a free exchange of ideas and proposals.

For the propagation payload there is, as already mentioned, an experimenters group OPEX chaired by ESA, involving all those who propose to make experiments and build equipment. Particular attention has been paid in this group not only to receiver design, but also to optimum and co-ordinated methods of data acquisition, processing and analysis. These latter aspects are of vital importance to ensure that the best scientific results are obtained from the measurement opportunity offered by the satellite. The activities of the OPEX group have resulted in two documents being issued by ESA, defining data-processing and analysis requirements.

An Earth-Station Working Group has been set up by those who are building or planning to build earth stations for the communications payloads. The members of this Group are drawn from PTT administrations, recognised private operators, educational and research establishments, and ESA. Delegations to the meetings are from Italy, The Netherlands, the United Kingdom, Canada, Denmark and Spain.

This Group has made considerable progress in defining the earth-station parameters necessary to support the various communications experiments within the Olympus Utilisation Programme. A document entitled 'Earth-Station Considerations for Olympus Communications Experiments' has been prepared and widely distributed. Discussions in the Group have already resulted in better definition of the experiments and identification of new possibilities, particularly in the area of fade countermeasures. A further document describing the ESA earth stations has also been prepared.

Many of the applications received are in the field of education and training. The number of separate organisations involved in this area is clearly a problem in terms of coordination and scheduling. ESA is therefore encouraging applicants to form self-coordinating groups offering a simpler interface to the Olympus schedules.

Conclusions

As witnessed by the above brief summary of the scope and content of current plans for use of Olympus, the requests for satellite time are already quite substantial for all payloads. Further applications for Olympus capacity are encouraged, but should be made promptly. A preliminary programme of activities has been drawn up for the first year of operation. A great deal of earth-station hardware is now under construction, and the satellite itself is nearing completion. Olympus should therefore certainly provide a worthwhile opportunity for all interested parties to design and test satellite communications and broadcasting techniques, thereby producing a substantial step forward towards the operational telecommunications systems of the future.

The Meteosat Exploitation Project*

J. de Waard, Project Manager, Meteosat Exploitation Project, European Space Operations Centre (ESOC), Darmstadt, Germany

Since the start of the Meteosat Operational Programme on 23 November 1983, many changes have been introduced both in its scientific and technical content, and in the legal framework under which it has had to be executed. The Programme, and particularly its exploitation aspects, as defined today are discussed here and the performance figures for the operational phase are presented. Further activities that will lead to an even more reliable and performant system are also reviewed.

* Based on a Presentation made at the Sixth Meteosat Scientific Users Meeting, 25—27 November 1986, Amsterdam.

Introduction

The Meteosat Programme became operational on 23 November 1983. Until the end of 1986, it was conducted within the Agency's legal framework under Article V.1(b) of the ESA Convention, i.e. as an Optional Programme. In the meantime, the Convention of the European Meteorological Satellite Organisation (Eumetsat) has been ratified, and this new European venture became a legal entity on the 19 June 1986. From 1 January 1987, therefore, the Meteosat Programme will be conducted under a special Agreement between Eumetsat and ESA, the latter's role now being governed by Article V.2 of its Convention (Operational Activities).

Eumetsat

Eumetsat is an International Organisation whose objectives are to:

> *'Establish, maintain and operate a European system of operational meteorological satellites'.*

All ESA Member States, apart from Austria, are Members of Eumetsat, and in addition countries like Finland, Greece, Portugal and Turkey have also joined this new organisation. This is a clear demonstration of today's international interest in satellite meteorology.

Eumetsat has entrusted the conduct of the Meteosat Operational Programme to ESA. Following the procurement and subsequent launching of the satellites, ESA's activities will be concentrated around the day-to-day operation of the satellites and their associated ground-based equipment. All such activities are conducted from ESA's European Space Operations Centre (ESOC), in Darmstadt, Germany. It should therefore be no surprise that Eumetsat has selected Darmstadt as the location for its new Headquarters, thereby facilitating close contact between the two bodies, from which the Meteosat Operational Programme can only benefit.

Programmatic aspects

Orbital configuration

At present the Programme still has to rely on the Meteosat F2 satellite, launched on 19 June 1981. This satellite was in fact originally designed for a lifetime of just three years. That it still supports the image-acquisition mission as well as the data-dissemination mission proves how solid the original design was and how efficiently the satellite has been operated since its commissioning. Fortunately, the data-collection mission, which until the autumn of 1985 was still supported by the Meteosat F1 satellite (launched in 1977!), could be taken over by Goes-IV, an American meteorological satellite made available for that purpose by the National Oceanic and Atmospheric Administration (NOAA).

The Meteosat Operational Programme includes the procurement and launch of three new satellites, designated MOP 1, MOP 2 and MOP 3. As the Ariane V18 launch failure on 31 May 1986 caused all subsequent launches to be delayed, launch of the MOP 1 satellite is currently scheduled for February 1988. To bridge the gap between now and the

Figure 1 — Planning milestones in the Meteosat Operational Programme

commissioning of that MOP 1 satellite, it has been decided to launch a spare prototype remaining from the Pre-Operational Programme, namely Meteosat P2. Its launch is currently scheduled for June 1987.

The overall picture is therefore as follows (Fig. 1):

1. Meteosat F2, in-orbit: image-acquisition and data-dissemination missions supported.
2. Goes-IV, in-orbit: data-collection mission supported until Meteosat P2 becomes operational.
3. Meteosat P2, to be launched June 1987: satellite fully compatible with those of the pre-operational series and will take over at least the data-collection mission as soon as it has been commissioned.
4. MOP 1, to be launched in February 1988: satellite more performant than those of the pre-operational type and will take over all missions once operational. This will make P2 available to support the trans-Atlantic atomic-clock-synchronisation experiment 'Lasso'. MOP 1 has a design lifetime of five years and will, following the launch of the next spacecraft, become available as an in-orbit spare.
5. MOP 2, to be launched in July 1989: designed, like all of the MOP series, for a lifetime of five years, it will take over the functions of MOP 1, provided all systems are performing according to specification.
6. MOP 3, not to be launched before 1990. With these satellites in orbit, an Operational Programme up to and including 1995 will be assured.

Studies have already been initiated within ESA for the so-called 'second-generation' meteorological satellites, the first of which is planned for launch around 1994. This should ensure continuation of the Operational Programme well beyond the year 2000.

Organisation of the Meteosat Exploitation Project (MEP)

The present MEP organisation was selected at the start of the Operational Programme in late 1983. It was logical at that time to structure the project around three divisions:

(i) Operations, subdivided into:
 — spacecraft operations
 — ground-segment operations
 — mission control, and
 — image quality control.

(ii) Data services, consisting of:
 — digital products, and
 — photographic products.

(iii) Meteorology, including:
 — science
 — meteorological information extraction, and
 — scientific support software.

The main objective for the Operational Programme was — and still is — to extract, quality-control and deliver the desired meteorological products in accordance with an agreed

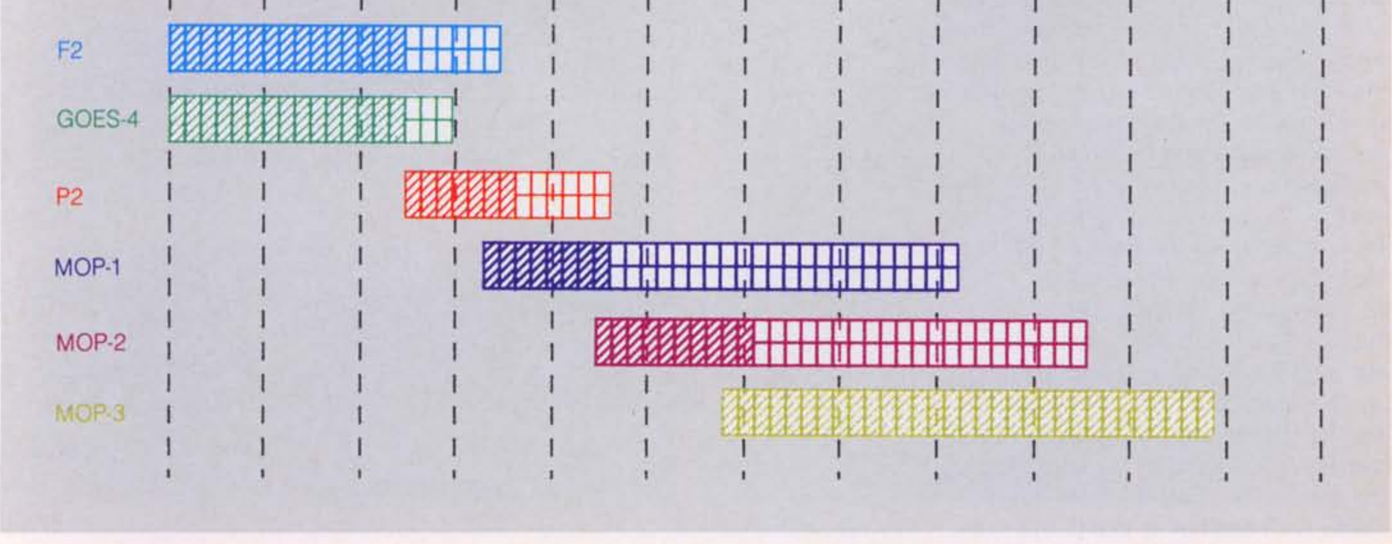


Figure 2 — Locations of Meteosat's visible (VIS), thermal-infrared (IR) and water-vapour (WV) channels

dissemination schedule. This involved many tasks and in particular a complete refurbishment of the ground segment had to be planned to achieve the level of operational reliability required for an operational programme. At the same time, the basic capabilities had to be extended to be able to handle the MOP-type data.

Successful exploitation of the Meteosat imagery data depends heavily on:

- timely availability of the derived products
- the quality of the products
- the inclusion of new products.

These features rely on ground-segment performance, which, in turn, is state-of-the-art dependent. New technology developments therefore have to be followed closely and some independent Meteosat-related research has to be conducted to be in a position to identify new applications (products) and at the same time guarantee ground-equipment compatibility. Hence, to stay competitive, certain research activities have to be maintained within the project. Some of these are dealt with in the following sections.

Meteorological products

The Meteosat satellites, which are spin-stabilised, are in an orbit with an altitude of 35 800 km and a period of 24 h. Their primary position is above the equator on the Greenwich Meridian. Their spin axis is normally kept perpendicular to the equatorial plane, and the orbital inclination controlled to within ±0.5°. The satellite's multichannel imaging instrument (radiometer) scans the Earth from east to west, the scanning motion being provided by the satellite's spin. A succession of image lines is obtained by stepping the radiometer telescope from south to north synchronously with the satellite spin period. The instrument allows Earth imaging with a resolution, at the subsatellite point, of 2.5 km in the visible (VIS) and half of that (5 km) in the infrared (IR) and water-vapour (WV) bands. An Earth image is generated every half an hour.

An improvement provided by the MOP-type satellites will be that the data from all the channels — two in the visible, one in the thermal infrared and one in the water-vapour band — will be transmitted to the ground station simultaneously (the resolution of all channels will also be upgraded to 8 bits).

Meteorological processing

The pre-processed rectified images from the visible, infrared and water-vapour channels are the basis for the quantitative determination of meteorological products. These channels are located (Fig. 2) in the solar spectrum (VIS) at 0.5—0.9 μm, in the window region of the thermal-infrared (IR) spectrum (10.5—12.5 μm) and in the water-vapour absorption band (WV) at 5.7—7.1 μm.

The rectified Meteosat image is divided into segments of 32×32 IR pixels (i.e. 160×160 km^2 at the subsatellite point), and processing is performed for all segments within a 55° great-circle arc around the subsatellite point. Although the IR radiances received at the satellite are indicative of the temperatures of the emitting surfaces, such as sea, land or cloud, corrections for atmospheric absorption and emission processes are necessary for quantitative studies. These corrections are based on a radiative-transfer scheme using the temperature and humidity data from the numerical forecast model of the European Center for Medium-Range Weather Forecasts (ECMWF) as input. Climatological background fields are also used as ancillary data.

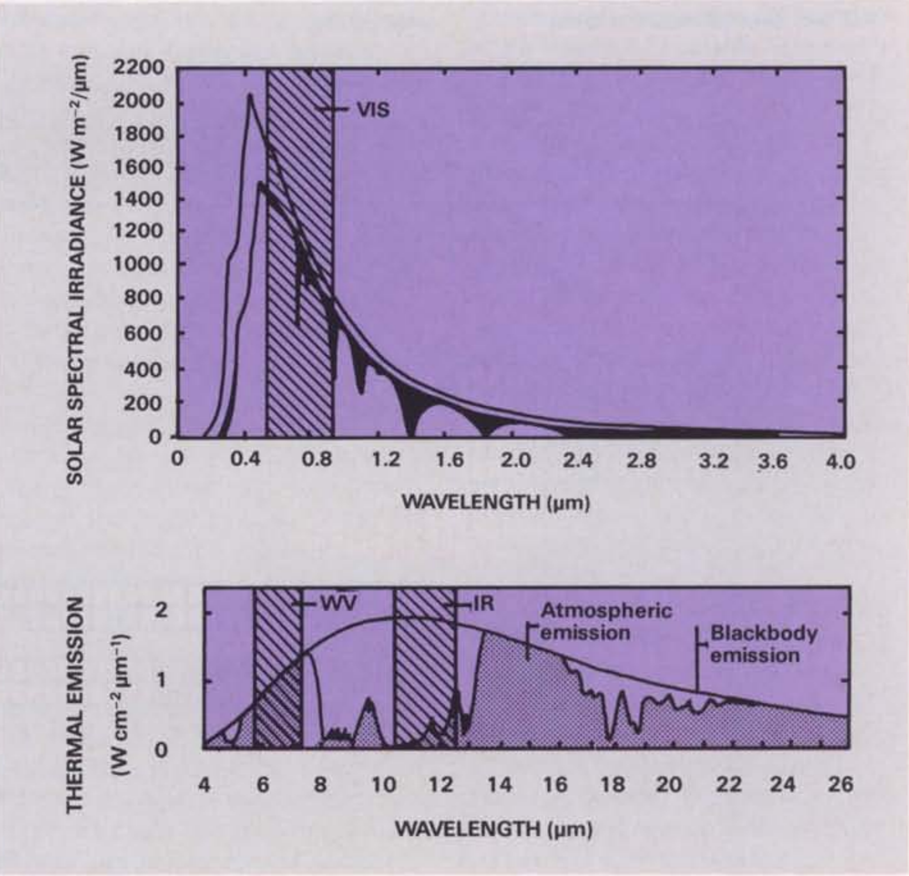


Figure 3 — Two-dimensional histogram of visible and infrared Meteosat data

Figure 4 — Cloud Motion Vectors (CMVs) derived from cloud displacements over three consecutive Meteosat images

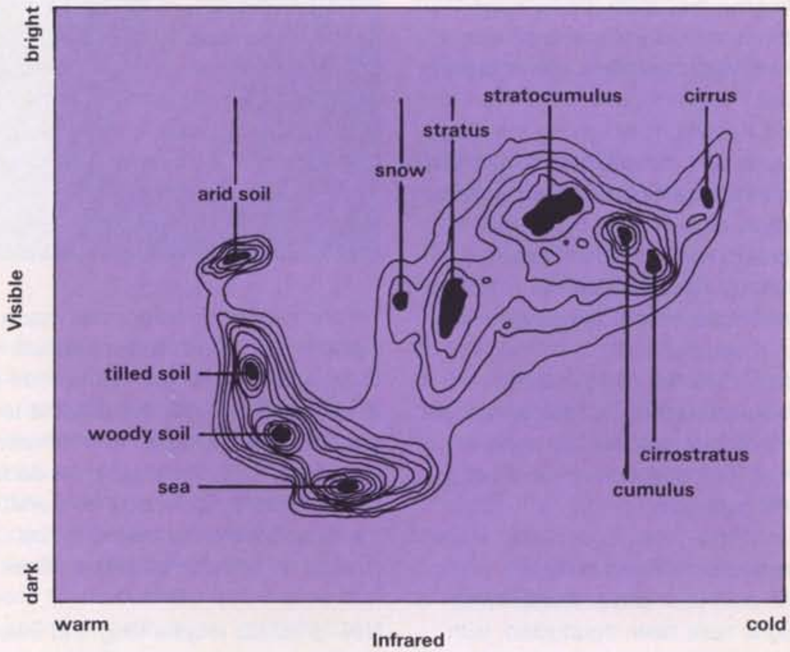
Figure 5 — Sea Surface Temperatures (SSTs) derived from Meteosat thermal-infrared channel data (11 μm)

For the quantitative meteorological analysis, two-dimensional histograms of IR and VIS and IR and WV data are constructed. The observed peaks in the histogram correspond to specific scenes, such as sea, low clouds and high clouds, in the satellite image, as illustrated in Figure 3. The derived peaks and their statistics (mean and standard deviation) are stored for further processing. The meteorological products for each segment are computed based on the results of the histogram analysis and after proper correction for atmospheric interference has been performed.

Current products

The meteorological products presently being generated at ESOC are:

1. Cloud Motion Vectors (CMVs), derived from the cloud displacements over three consecutive images, thus providing a mean wind over a 60 min period (Fig. 4).
2. Sea-Surface Temperatures (SSTs), based on the principle that the 11 μm radiation emitted by a body can be related to its surface temperature, after corrections for atmospheric absorption (Fig. 5).
3. Upper Tropospheric Humidity (UTH), derived primarily from the water-vapour-channel data (Fig. 6).
4. Precipitation Index (PI), which has been included on an experimental basis and is based on the assumption that the colder the cloud top, the



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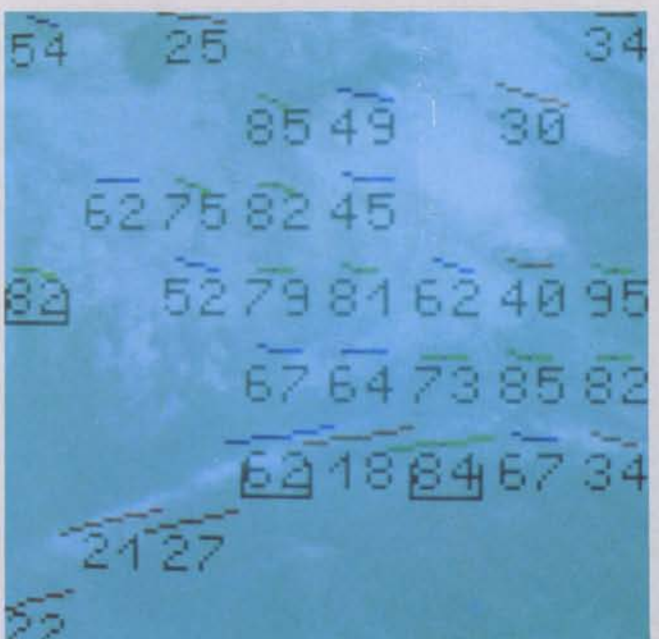

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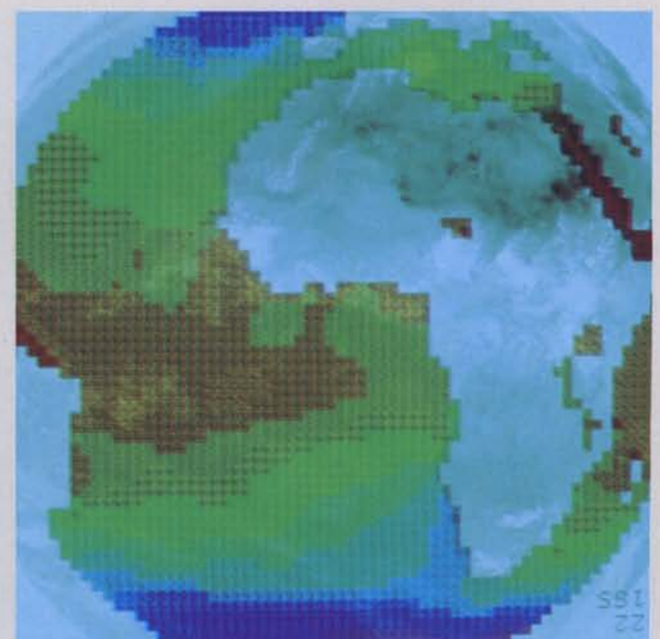

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Figure 6 — Upper Tropospheric Humidity (UTH) derived primarily from Meteosat water-vapour channel data

Figure 7 — Cloud Analysis (CA) data derived from Meteosat

higher the probability that it rains. It gives an estimate of the accumulated convective precipitation over a five-day period.

5. Cloud Analysis (CA), giving the cloud amounts and cloud-top temperatures for up to three cloud clusters within a segment (Fig. 7).
6. Cloud-Top Height (CTH), based on IR radiances, corrected with WV data. The CTH describes clouds within each 4×4 pixel array.
7. Climate Data Set (CDS), which provides a summary of the results of the histogram processing, together with all the corrections performed on the IR radiances.

Improvements and new products

Over the past year or so, several wind campaigns have been conducted, with the support of some of the national weather services, with emphasis on high-level winds. As a direct result, quality control could be improved through the provision of more background information (mainly ECMWF-provided temperature and humidity profiles). In addition, the visual presentation of the relevant data on the screen was improved to assist the Shift Meteorologist. Further improvements were subsequently studied by the ESOC/MEP scientists, leading to the introduction of a windowing technique, which resulted in a considerable reduction in the previous high-level-wind bias.

Yet another improvement was made in surface- and cloud-top-temperature determination, with the introduction of an efficient radiative transfer scheme to calculate the necessary atmospheric correction. The latter has to be added to the equivalent black-body temperature at the satellite's level to yield the true surface and cloud-top temperatures.

New products require long and extensive validation before aquiring operational significance. The Precipitation Index mentioned earlier is a good example. The ESOC Precipitation Index (EPI) was introduced on an experimental basis in 1986, and validation activities have been in progresss ever since. They will be continued during 1987 using ground-truth data supplied from Burkina Faso in Africa.

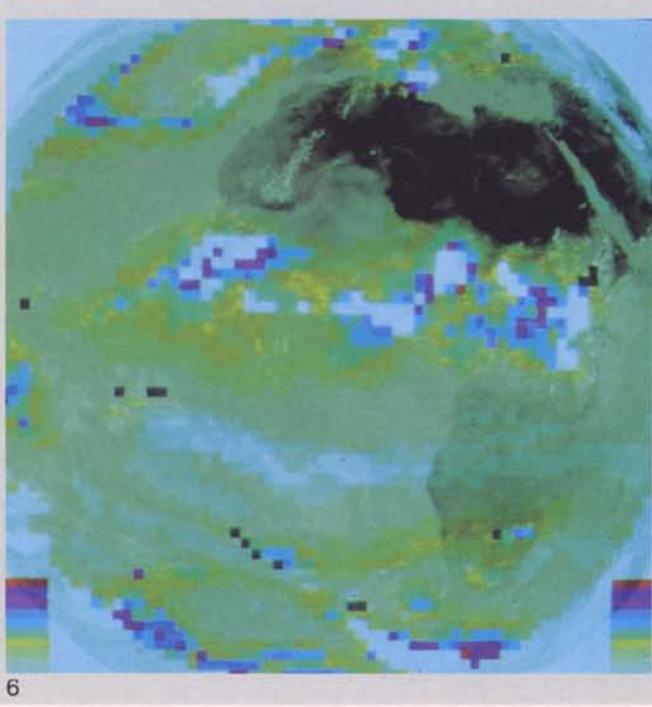
Operations

At present, all Meteosat operations, with the exception of the launch phase, are carried out by the MEP team on a round-the-clock basis.

The present ground-segment configuration consists of the:

- Data Acquisition, Telecommand and Tracking Station (DATTS)
- Data Transmission and Routing System (DTRS)
- Meteosat Ground Computer System (MGCS)
- Meteosat Operations Control Centre (MOCC), shown in Figure 8
- Meteorological Information Extraction Centre (MIEC) and
- Control Receive Station (CRS).

The present capabilities are limited to the control of one operational satellite, supporting the three basic missions (imagery, dissemination and data



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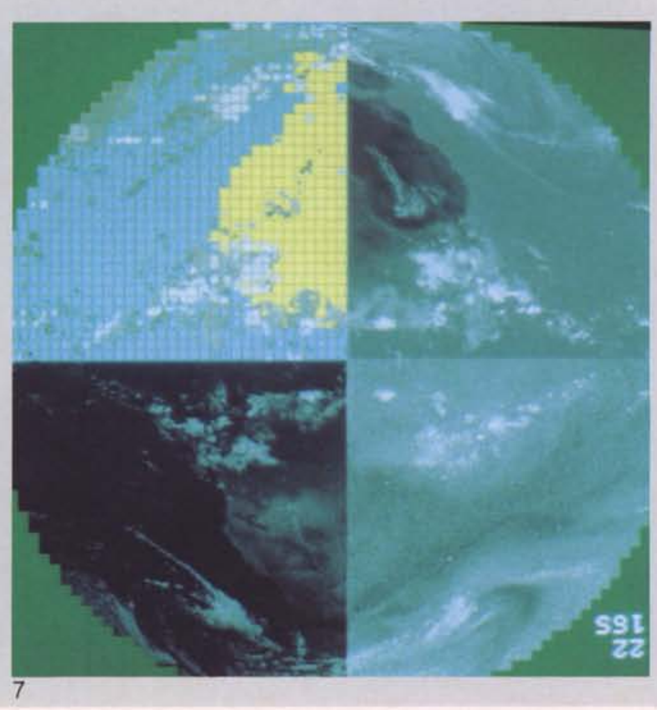

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Figure 8 — View of the Meteosat Operations Control Centre (MOCC) at ESOC, in Darmstadt

collection), and one hibernating satellite. These capabilities will be extended so that two hibernated spacecraft can be controlled.

The facilities will also be extended to make them compatible with the MOP-type satellites well before the first in this series is launched. In particular, this will involve the inclusion of a new 'Meteorological Data Dissemination' (MDD) mission, which will allow the relay of vital meteorological data to African and Middle-Eastern States. The system will have two digital channels (each 2.4 kbit/s), one of which will be used for the transmission of digital fascimile-type data. The other will provide for the relay of alphanumeric data such as DCP messages, SATOB, SATEM, ASDAR, and ASAPs and some selected SYNOPS and TEMPS. The installation of new ground-support equipment will have to be performed in parallel with the refurbishment of the existing equipment, whilst still maintaining day-to-day operations.

Aside from the operational demands, the reliability of the overall system is to be further improved. Improvements are foreseen in the MOCC which are related mainly to the provision of additional facilities for the duty staff, such as:

1. The use of graphics, enabling real-time display of the configuration in use.
2. Software control of the procedures to be executed. This could include composition of the procedure and automatic step-by-step execution under operator supervision.
3. The building of a Proficiency Training Facility (PTF) for operator training. This facility could also be used for the development and qualification of operational procedures.
4. Further use of artificial intelligence in support of the decision-making process, in particular by providing advice to the operator in the case of an anomaly, such as an indication of the most likely cause of the anomaly and the recommended recovery procedure.

The other operational domain that requires improvement is that of the service to the users. Such improvements, not being covered by the present inter-agency agreement, will require Eumetsat's approval prior to their implementation. Several studies have already been performed which have yielded promising results. Most of these are described in the following paragraphs.

Real-time rectification

The rectification process is time-consuming but necessary in order to relate pixel data always to the same geographical area, which is a must for quantitative use of the data. At present, rectification can only be initiated after the complete image has been received. Analyses of the rectification process have confirmed that the disturbing forces causing the 'instabilities' in the data are periodic in nature. Hence, a statistical analysis of the rectification matrix computed for the last series of slots allows prediction of the rectification matrix for the next slot, and thus facilitates rectification of the incoming pixel in real time. A time-saving of 25 min can be achieved if this system of real-time rectification can be introduced.

Real-time dissemination

Real-time rectification can only be used to full advantage if introduced together with a real-time dissemination scheme, which will have to be digital in nature. The real-time rectified imagery data could be grouped in blocks of lines and disseminated in near-real-time. These data packages could be interleaved with all the other meteorological data available at ESA/ESOC, such as the MIEC products. This would mean that one satellite data-dissemination channel would contain all high-resolution data as well as all the MIEC products.

Data-compression techniques have been studied that enable handling of even the higher bit rates of the MOP satellites in this way (without loss of information). Forward-error-correcting coding could be added to improve the reliability of the dissemination link. This in turn could lead to a simplification of the Primary Data User Station (PDUS) front end. Together with the software required for the decommutation and de-coding of the data, it would enable standardisation of a major part of the station hard- and software. This would lead to higher production rates and consequently to a reduction in cost. It is believed that the cost of such a PDUS station will finally approach that of an extended Secondary Data User Station (SDUS, often referred to as a WEFAX station).

System aspects

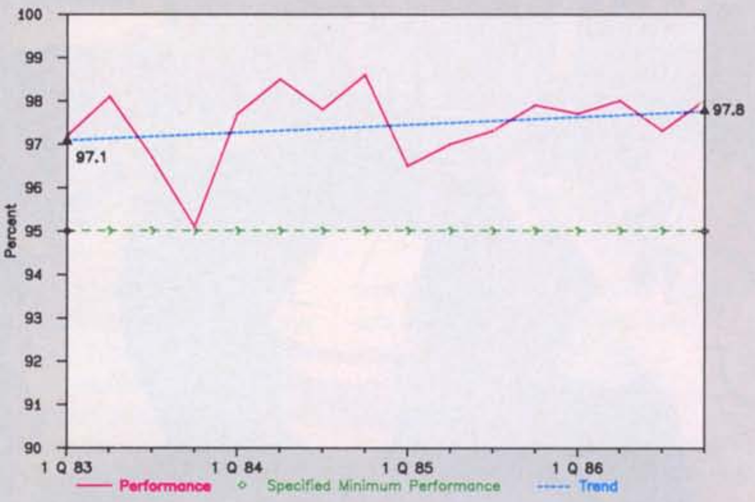
The impact of such a new dissemination system would be considerable. Firstly, all data could be disseminated on one channel, leaving the second channel free to continue the present WEFAX mission for as long as it is required.

Secondly, each user could select from the data received those areas and/or meteorological products of particular

Figure 9 — Quarterly performance average (image acquisition, data collection and dissemination) for the Meteosat Exploitation Project (MEP)

Figure 10 — Quarterly performance average (CMV, SST, UTH, CA and CTH) for the Meteorological Information Extraction Centre (MIEC)

Figure 11 — Quarterly performance variations for Meteosat missions and products for the period 1983—1986



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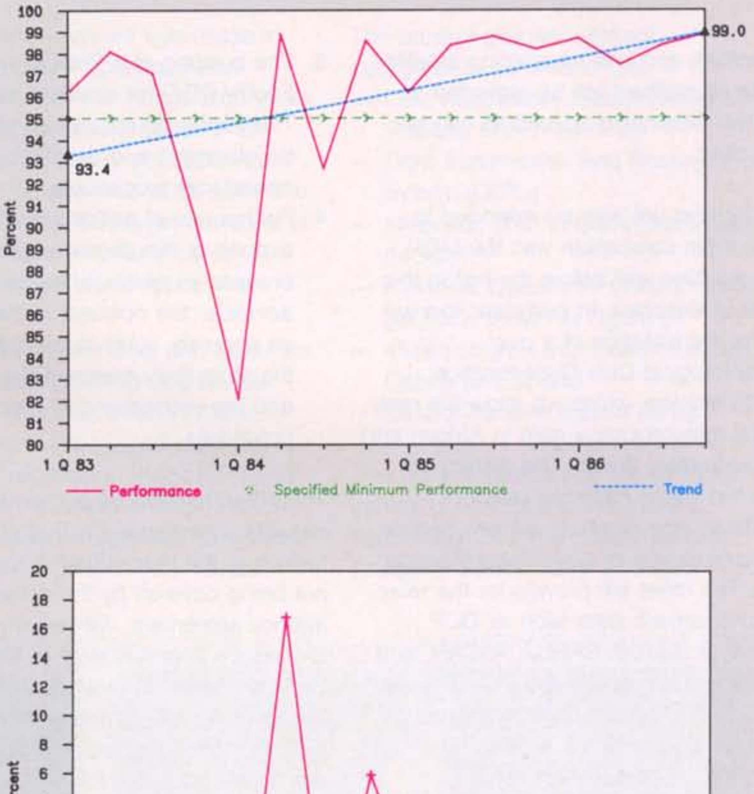

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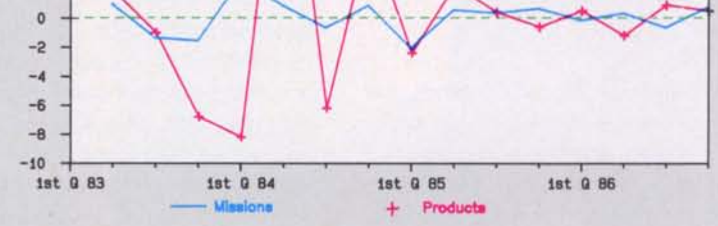

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interest. This would include selection of the presently disseminated WEFAX areas.

Thirdly, all users would have access to data of the highest quality without having to invest more than is currently spent on a 'second quality level' reception station.

Future system performance

The performance figures for the overall system as specified by Eumetsat are:

1. The ground system shall permit the acquisition of more than 96% of the theoretical number of images that could be acquired under normal circumstances.
2. At least 95% of the acquired images have to be processed and shall meet the required accuracy criteria.
3. The availability of all products and services to the users shall be ≥95% on a monthly basis.

That these figures are met by the MEP is clearly demonstrated in Figures 9, 10 and 11.

Figure 9 illustrates the average mission performance (image acquisition, data collection and dissemination) on a quarterly basis. Note the positive slope of the performance trend-line.

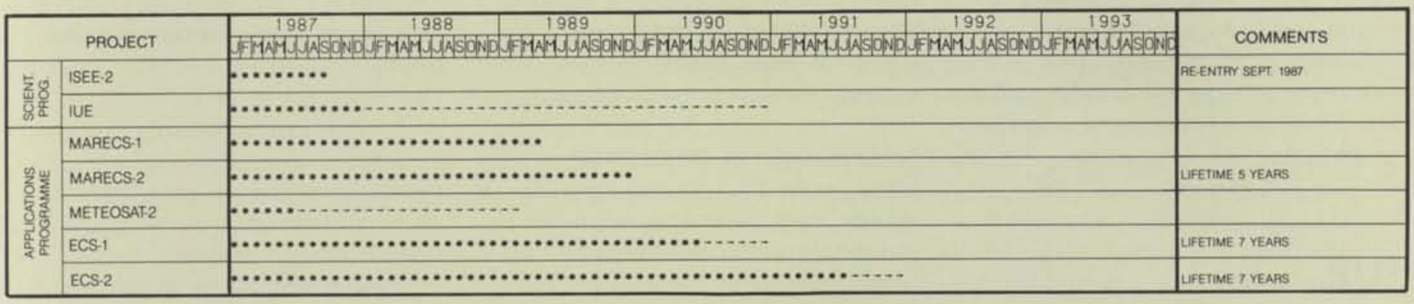
Figure 10 shows the performance of the MIEC, averaged over the derived products (CMV, SST, UTH, CA and CTH). The positive effect that replacement of the old MIEC equipment by an entirely new system during the first quarter of 1985 had on performance is clearly demonstrated. Since that date, performance has been continuously maintained above the specified minimum level.

Finally, Figure 11, which shows the variations in performance again on a quarterly basis, demonstrates improved quality stability over the years. Performance has been constantly high over the past year and a half, a must for an operational programme.

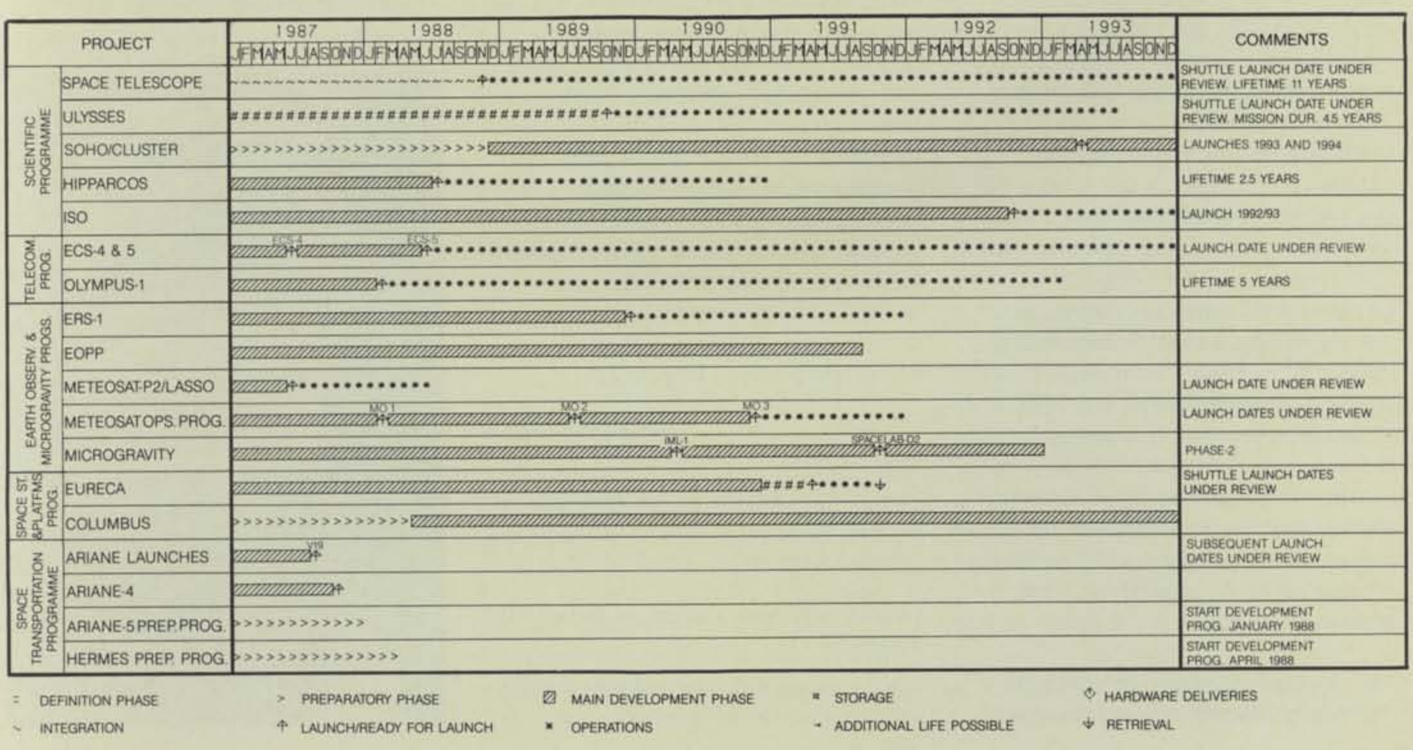
The further improvements outlined in this article will undoubtedly lead to even better performance levels as down-times due to operational problems are reduced by greater use of artificial intelligence and the increased alertness of the operators as a consequence of the new sophisticated proficiency training tools.

Programmes under Development and Operations / Programmes en cours de réalisation et d'exploitation

In Orbit / En orbite



Under Development / En cours de réalisation



ISEE

La collecte de données du couple ISEE-1 et 2 a continué, à une rythme quelque peu ralenti, sur le réseau de saisie de données de la NASA. Sur le plan technique, les deux satellites se comportent bien, encore que les performances du générateur solaire d'ISEE-2 soient devenues marginales. Lors de leur rentrée dans l'atmosphère prévue en septembre de cette année, ils auront passé dix ans moins un mois en orbite.

Le satellite ICE (anciennement ISEE-3), continue à graviter autour du Soleil. Les performances techniques sont bonnes, mais la collecte de données est négligeable à cause du faible débit binaire disponible.

L'exploitation scientifique des données reçues antérieurement est encore importante pour chacun des trois satellites, à en juger par le flot incessant des publications et des présentations aux conférences.

IUE

Le 26 janvier 1987, IUE a entamé sa dixième année en orbite. Les performances du satellite sont bonnes, et les opérations scientifiques se sont déroulées normalement. On a procédé à une remise en état, attendue depuis longtemps, de l'antenne de liaison ascendante VHF, sans perte du temps d'observation européen, malgré quelques complications imprévues. A la fin de 1986, on a constaté un mauvais fonctionnement de l'une des deux batteries embarquées, mais les résultats des premiers essais indiquent qu'elles sont encore pleinement opérationnelles.

La réponse à l'appel aux propositions pour la dixième année d'observations d'IUE a montré que l'intérêt des milieux scientifiques restait grand. Les 201 propositions reçues correspondent à 2,6 fois le temps d'observation disponible. Le comité chargé de l'allocation du temps d'observation s'est réuni début mars pour évaluer ces propositions et de répartir le temps disponible (et limité) — tâche toujours difficile!

Les récents événements scientifiques marquants comprennent la découverte de soufre neutre à proximité de la surface du satellite de Jupiter, Io, qui a des implications importantes pour le mécanisme de formation de ce que l'on appelle le 'tore de Io', l'un des phénomènes les plus mal élucidés du système solaire.

L'absence de raies interstellaires étroites d'espèces fortement ionisées dans les spectres à haute résolution du noyau NGC 1705 a des conséquences importantes pour les théories de la formation des raies dans les QSO (objets quasi-stellaires) à larges raies d'absorption, et pourrait conduire à établir un lien entre ces objets de type 'sursauts' stellaires proches et les QSO cosmologiques.

La souplesse des procédures d'observation d'IUE a encore été très utile dans les observations de diverses cibles occasionnelles, telles que GK Per la première nova ancienne à être observée en éruption dans l'ultraviolet.

Sur le plan général de l'assistance à IUE, il y a lieu de mentionner que les résultats de l'évaluation de la fonction de transfert d'intensité nouvellement déterminée pour la Caméra à grande longueur d'onde (LWP) ont montré que l'on pouvait améliorer considérablement le rapport signal/bruit dans la région 2000—2500 Å. D'autre part, on a terminé les observations permettant un nouvel étalonnage absolu des instruments scientifiques, et de nouveaux étalonnages sont en préparation. On est en train de procéder aux dernières opérations de mise en circulation d'un nouveau produit, 'l'archive à faible dispersion uniforme' (ULDA), qui représente une forme tassée des données de la base de données générale. Cela devrait faciliter considérablement l'accès aux données d'IUE. Les derniers préparatifs pour rendre l'ULDA accessible par l'intermédiaire de réseaux d'ordinateurs en Europe sont en bonne voie.

Si les opérations se poursuivent sur cette voie, et si IUE continue à fournir des résultats scientifiques uniques et valides, une proposition sera formulée pour prolonger les opérations jusqu'en 1988. Cette proposition, ainsi que le plan post-opérationnel seront présentés à la réunion du Conseil directeur des programmes scientifiques prévue en mai.

Météosat

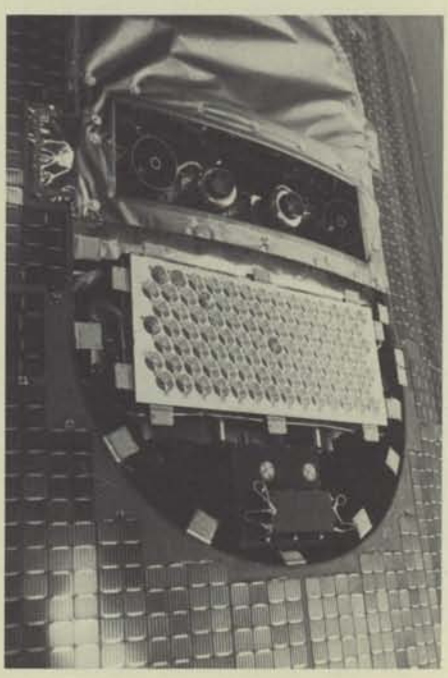
Programme pré-opérationnel

Le satellite P2 est encore entreposé chez le maître d'oeuvre à Cannes, de même que le matériel Lasso qui a été installé dans le satellite. Le rétroréflecteur Lasso a été entreposé séparément pour réduire au minimum la dégradation de ses surfaces optiques.

Programme Météosat Opérationnel (MOP)

Les travaux sur les unités de vol se poursuivent à l'Aérospatiale à Cannes, où les satellites seront terminés et, si nécessaire, entreposés dans l'attente d'une occasion de lancement. Du fait du retard subi par le calendrier des lancements Ariane, une installation spéciale pour l'entreposage du matériel MOP a été apprêtée à l'Aérospatiale.

Malgré quelques problèmes mineurs rencontrés au cours de l'intégration et des essais, on a pu les résoudre sans que le programme principal des travaux s'en ressente.



Lasso retro-reflector array on the Meteosat-P2 spacecraft

Réseau rétroréflecteur de l'expérience Lasso installé sur satellite Météosat-P2

ISEE

Data collection from the ISEE-1/ISEE-2 spacecraft pair has continued, with a somewhat reduced priority in NASA's data-acquisition network. From an engineering point of view, both spacecraft are performing well, although ISEE-2 now has marginal solar-panel performance. At the time of the predicted re-entry of these two spacecraft in September this year, they will have completed one month less than 10 years in orbit.

The ICE spacecraft (formerly ISEE-3) continues to orbit around the Sun. In engineering terms, ICE is performing well, but no meaningful data collection is possible at the low bit rate available.

The scientific activity on past data is still high for all three spacecraft, judged on the basis of the continuing publications and presentations at conferences.

IUE

On 26 January IUE started its tenth year of orbital operations. The spacecraft is performing well and scientific operations have proceeded normally. A long-overdue overhaul of the VHF uplink antenna has been conducted without loss of European science time, even though some unforeseen complications were encountered. One of the on-board batteries developed a malfunction late last year, but the results of the first tests indicate that both batteries are still fully operational.

The response to the Call for Proposals for the tenth year of IUE observing have shown that the scientific community's interest in IUE observations remains high. The 201 proposals received correspond to 2.6 times the available observing time. The IUE Time Allocation Committee met in early March to evaluate these proposals and perform the always difficult task of allocating the limited time available.

Recent scientific highlights include the discovery of neutral sulphur very close to the surface of the Jovian satellite Io, which has important implications for the formation mechanism of the so-called 'Io Torus', one of the poorly understood phenomena in our solar system.

The absence of narrow interstellar lines of highly ionised species in the high-resolution spectra of the nucleus NGC 1705 has important consequences for the theories of the formation of the broad lines in the broad absorption-line QSOs, and might lead to a connection between such nearby starburst-like objects and the cosmological QSOs.

The flexibility of IUE's observational procedures has again been very useful in the observations of various targets of opportunity, such as GK Per, the first old nova to be observed in outburst in the ultraviolet.

In the general area of IUE support, it is worth mentioning that the results on the evaluation of the newly determined intensity transfer function for the operational long wavelength camera (LWP) have shown that considerable improvements in signal-to-noise ratio can be obtained in the 2000–2500 Å region. Also, the observations for a new, absolute calibration of the IUE scientific instruments have been completed, and these new calibrations are in preparation. The final steps are being taken to release a new IUE product, the Uniform Low-Dispersion Archive (ULDA), which represents a compacted form of the data in the general IUE database. This is expected to facilitate access to IUE data considerably. The final preparations for making the ULDA accessible via computer networks in Europe are in progress.

If spacecraft operations continue as well as at present and IUE continues to provide unique and valid scientific output, a proposal will be made to extend IUE operations through 1988. This proposal, and the plan for IUE's post-operational phase, will be presented at the May meeting of the Agency's Science Programme Committee (SPC).

Meteosat

Preoperational programme

The Meteosat-P2 spacecraft is still in storage at the Prime Contractor's facility in Cannes, as is the Lasso equipment that has been installed in the spacecraft. The Lasso retroflector has been stored separately to minimise degradation of its optical surfaces.

Meteosat Operational Programme (MOP)

Work on the flight units is continuing at Aerospatiale in Cannes (F), where the satellites will be completed and if necessary stored awaiting a launch opportunity. In view of the delayed overall Ariane launch schedule, a special facility for the storage of MOP hardware has been made ready at Aerospatiale.

Minor problems have been experienced during integration and testing, but these have been overcome without affecting the main programme of work.

Ground segment

Satellite operations

On 11 December 1986 an inclination manoeuvre was performed to return the Meteosat-F2 satellite's orbital plane to 0.15° with respect to the equator. This, together with the upgrading of the rectification software (now performing to at least 2° inclination), will extend the satellite's lifetime considerably, in fact up to February 1989 (providing ageing effects do not deteriorate other satellite subsystems). The satellite, originally designed for a three-year lifetime, has been operating since 19 June 1981. The performance of its main instrument, the radiometer, is still excellent. A decontamination manoeuvre has been proposed to increase its IR sensitivity, which is showing some effects of ice contamination. These effects can easily be counteracted by the decontamination manoeuvre.

The Data-Collection Platform (DCP) mission will be further supported by the GOES-IV satellite until the arrival of the Meteosat-P2 spacecraft, currently scheduled for launch in early 1988.

Meteorological data processing

Installation of the new cloud-motion-vector extraction program has taken place. This program, making use of a newly developed windowing technique, provides more accurate wind extraction, especially for high-level winds. In addition, a new atmospheric-correction scheme has been implemented, providing increased operational flexibility. The improvements that the new schemes provide are being analysed and it is expected that they can be declared operational before the end of March.

In addition, a new cloud-top-height product has been developed, consisting

Secteur terrien

Opérations du satellite

Le 11 décembre 1986, on a procédé à une manoeuvre d'inclinaison pour remettre le plan orbital du satellite Météosat-F2 à 0,15° par rapport à l'équateur. Cette manoeuvre, ainsi que l'augmentation de puissance du logiciel de rectification (qui fonctionne maintenant jusqu'à une inclinaison d'au moins 2°), prolongera considérablement la durée de vie du satellite, en fait jusqu'à février 1989 (à condition que des effets de vieillissement ne détériorent pas d'autres sous-systèmes). Le satellite, conçu à l'origine pour une durée de vie de trois ans, est exploité depuis le 19 juin 1981. Les performances de son instrument principal, le radiomètre, sont encore excellentes. Il a été proposé de procéder à une manoeuvre de décontamination pour accroître sa sensibilité IR, qui présente actuellement certains effets de contamination par la glace. Ces effets peuvent être aisément contrecarrés par la manoeuvre de décontamination. La mission de la plate-forme de collecte de données (DCP) sera en outre assistée par le satellite GOES-IV jusqu'à l'arrivée de Météosat-P2, dont le lancement est actuellement prévu pour début 1988.

Traitement des données météorologiques

L'installation du nouveau programme d'extraction des vecteurs mouvement de nuages a eu lieu. Ce programme, qui fait appel à une technique de 'fenêtrage' nouvellement mise au point, permet une extraction plus précise des données relatives au vent, notamment pour les vents forts. De plus, on a mis en oeuvre une nouvelle méthode de correction des données atmosphériques, permettant une plus grande souplesse d'opération. Les améliorations apportées sont analysées et devraient être déclarées opérationnelles avant fin mars 1987.

De plus, on a mis au point un nouveau produit (altitude du sommet des nuages) consistant en deux tracés qui se chevauchent et qui couvrent les régions tropicales (30°N -30°S, 50°E -50°W).

Réaménagement du secteur terrien

Les travaux de réaménagement des stations sol se déroulent conformément aux plans nouvellement élaborés, qui exigent que les stations soient prêtes, notamment que leur puissance soit augmentée pour prendre en charge les satellites du Programme Météosat Opérationnel (MOP), avant le lancement de Météosat-P2.

EOPP

Les activités du programme préparatoire d'observation de la terre sont concentrées sur quatre secteurs principaux: Météosat de seconde génération, mission 'solide terrestre', plate-forme méridienne, et campagnes aéroportées. Suites au séminaire de Hohenschwangau en Allemagne, et à des réunions ultérieures avec la communauté scientifique, des rapports sont en cours de préparation pour l'appareillage scientifique relatif à l'étalonnage du Soleil, les petits instruments d'optique, et le détecteur des éclairs de foudre.

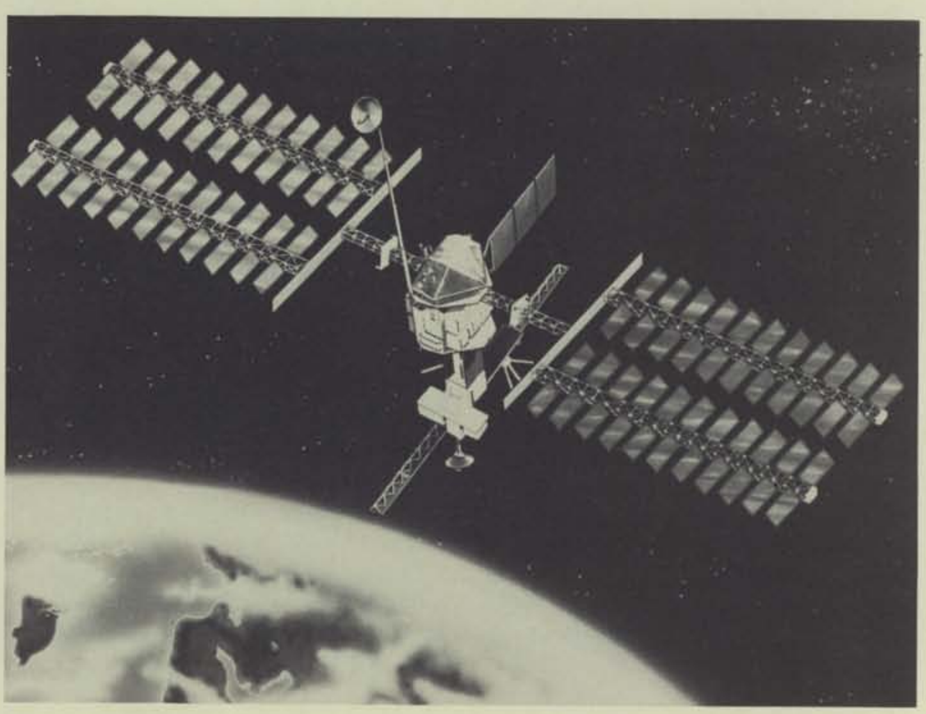
Lors d'un séminaire spécialisé sur les instruments opérationnels des satellites Météosat de seconde génération tenu à Ravenne (Italie), les conditions requises des instruments ont été définies et seront utilisées comme points de départ pour les études industrielles.

En ce qui concerne les missions 'solide terrestre', les offres industrielles pour les études préalables à la phase A d'une solution de rechange 'toute européenne' ont été reçues et sont à l'examen. En parallèle, on explore également les possibilités d'une mission conjointe ESA-NASA.

Pour la plate-forme méridienne, on est en train d'établir les conditions requises de la mission et le cahier des charges avant d'engager de nouvelles études industrielles sur l'instrumentation.

Un groupe de travail spécial 'Observation de la Terre' a été créé par des participants au projet Station spatiale internationale pour coordonner, en particulier, la fourniture des instruments, leur mise en place, l'accès aux données et les offres de participation pour les futures missions de la plate-forme méridienne. Ce groupe s'est déjà réuni à quatre reprises et a établi, entre autres, une liste préliminaire d'instruments pour les premières plates-formes, l'une dite 'du matin' pour l'Europe, l'autre 'de l'après-midi' pour les Etats-Unis.

Des plans de campagnes aéroportées sont en cours d'élaboration, principalement en coopération avec le Centre commun de Recherches de la



Artist's impression of the Polar Platform

Vue imaginaire de la plate-forme méridienne of two overlapping formats covering the tropical regions (30°N—30°S, 50°E—50°W).

Ground-segment refurbishment
Ground-station refurbishment work is proceeding according to the newly developed plans, which call for station readiness, including the required upgrading for MOP satellite support, before the launch of Meteosat-P2.

EOPP

Activities in the Earth-Observation Preparatory Programme (EOPP) are concentrated on four main areas: Second-Generation Meteosat, a Solid-Earth Mission, the Polar Platform, and Airborne Campaigns. Following the Hohenschwangau Workshop in Germany, and subsequent meetings with the scientific community, reports are being prepared for the scientific package covering Sun calibration, small optical instruments, and lightning flash detector. A dedicated Workshop on the operational instruments of the second-generation Meteosat satellites was held in Ravenna, Italy. At this meeting, the instrument requirements were defined, and these will be used as inputs for the industrial studies.

Concerning Solid-Earth Missions in preparation, the industrial offers for the pre-Phase-A studies of an alternative European-only solution have been received and are under evaluation. In parallel with this activity, the possibilities of a joint ESA/NASA mission are also being investigated.

For the Polar Platform, mission requirements and technical specifications are being established prior to further industrial studies on the instrumentation.

A special Working Group has been created by the Earth Observation representatives of the International Space Station Partners to coordinate, in particular, instrument provisioning, accommodation, data access and Announcements of Opportunity for the future Polar-Platform missions. This Working Group has already met on four occasions and has established, inter alia, a preliminary instrument list for the first European Morning and US Afternoon Polar Platforms.

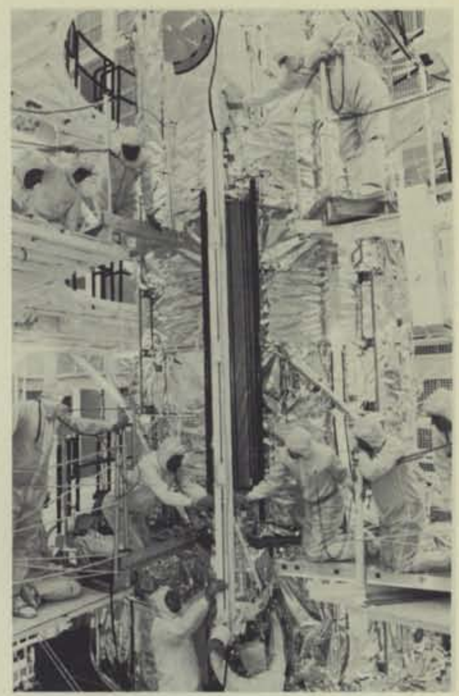
Plans for airborne campaigns are being established mainly in cooperation with the European Community Joint Research Centre, Ispra (Italy). The first campaign, called 'Agriscatt', aimed at characterisation of microwave signatures of various landscapes, is due to start in the Spring.

Space Telescope

NASA
Testing and reworking of the Space Telescope continues at the contractor's integration site in California. A six-month period of reduced activity on the Space Telescope is now planned based on the new launch date of 17 November 1988.

Solar array
A series of electrical tests on the solar-array deployment motors has been successfully conducted. It is planned to remove the solar-array wings during the second quarter of 1987 to allow the spacecraft side of the interface to be reworked.

Faint Object Camera
The Faint Object Camera (FOC) continues to function without problem during its monthly testing. Preparations have been made for the first operation of the FOC through a satellite link to the ground system at Goddard Space Flight Center (GSFC). The FOC will be removed from the Space Telescope during the second quarter of 1987, when an in-air calibration of the instrument is planned.



L'aile du générateur solaire du Télescope spatial chez Lockheed/MSC

Space Telescope solar-array wing at Lockheed/MSC

Ulysses

The conflict between Ulysses and the NASA Galileo mission for the late-1989 launch slot is still unresolved and currently both projects are being prepared for that date. A meeting between ESA and NASA is scheduled for early April to discuss, and hopefully resolve, this issue.

Technically, work continues on the definition of launch-vehicle interfaces and resolution of the many problems that inevitably arise when changing from one Upper Stage to another of completely different dimensions and characteristics. Good progress is being made on these and there is no reason to doubt the ability of the spacecraft and of the IUS/PAM-S rockets to be ready for the late-1989 launch opportunity, if this can indeed be allocated to Ulysses.

Soho/Cluster

The Solar Terrestrial Science Programme (Cluster/Soho) was endorsed by the ESA Science Programme Committee (SPC) in February 1986. Implicit in this endorsement was the need to pursue cost reductions in the Programme, with the objective of reaching an acceptable level for approval. To achieve this end, studies were undertaken to descope, technically, the content of the programme and to increase the international (USA/NASA) programme contribution. These studies were performed in collaboration with a Science Advisory Group and by the end of last year it was possible to propose a programme baseline to the SPC that reflected a significant expected cost reduction.

In addition to the expanded cooperation with NASA, an ESA/IKI (USSR) bilateral agreement is being pursued, concerning

Communauté européenne d'Ispra, en Italie. La première campagne, baptisée 'Agriscatt' et portant sur les signatures hyperfréquences de divers paysages, doit débuter au printemps 1987.

Télescope spatial

NASA
Les essais et la réfection du Télescope spatial se poursuivent dans l'installation d'intégration du contractant en Californie. Une période d'activité réduite de six mois est maintenant prévue du fait de la nouvelle date de lancement fixée au 17 novembre 1988.

Générateur solaire
Une série d'essais électriques sur les moteurs de déploiement des panneaux solaires a été effectuée avec succès. Il est prévu de déposer les ailes du générateur solaire dans le courant du second trimestre de 1987 pour permettre la réfection du côté satellite de l'interface.

Chambre pour objets faibles
Cette chambre (FOC) a continué de fonctionner sans problèmes au cours de ses essais mensuels. Des préparatifs ont été faits pour la première mise en service de la FOC par l'intermédiaire d'une liaison par satellite avec le système au sol du Centre de Vols spatiaux Goddard (GSFC). La FOC sera déposée du Téléscope spatial dans le courant du second trimestre de 1987, date à laquelle un étalonnage de l'instrument dans l'air est prévu.

Ulysse

Le confilt entre les missions Ulysse (ESA) et Galileo (NASA) pour le créneau de lancement de la fin 1989 n'est pas encore résolu, et à l'heure actuelle on prépare les deux projets pour cette date. Une réunion est prévue début avril entre les deux Agences pour débattre de ce problème et, espérons-le, le résoudre.

Techniquement, les travaux se poursuivent sur la définition des interfaces avec le véhicule de lancement et la résolution des nombreux problèmes qui se posent inévitablement quand on passe d'un étage supérieur à un autre ayant des dimensions et des caractéristiques totalement différentes. De grandes progrès sont actuellement faits, et il n'y a pas de raison de douter que le satellite et les fusées IUE/PAM-S seront prêts pour le lancement prévu à la fin de 1989, si cette date peut en fait être attribuée à Ulysse.

Soho/Cluster

Le 'Programme d'étude des relations Soleil/Terre' (Cluster/Soho) a reçu l'aval du Conseil directeur des programmes scientifiques (SPC) de l'ESA en février 1986. Cet aval impliquait la nécessité de continuer à rechercher des réductions de coût dans le programme, avec pour objectif d'atteindre un niveau acceptable pour l'approbation. A cette fin, des études ont été entreprises pour resserrer, au plan technique, le contenu du programme, et pour accroître la contribution internationale (NASA) au programme. Ces études ont été menées en collaboration avec un 'groupe consultatif scientifique', et à la fin de 1986 il était possible de proposer au SPC une base de référence de programme [Réf. ESA/SPC(86)21] qui reflétait une réduction importante des coûts prévus.

Outre l'extension de la coopération avec la NASA, un accord bilatéral ESA-IKI (URSS) est cours de négociation, concernant la fourniture éventuelle, par l'URSS, de deux satellites Cluster supplémentaires, à titre de coopération complémentaire dans le cadre du STSP. Pour définir la nature spécifique de cette collaboration, des groupes de travail conjoints ont été créés sous la direction d'un 'comité directeur conjoint'. Ces groupes de travail remettront aux directions de l'ESA et de l'IKI, d'ici fin 1987, les rapports conduisant à la définition d'une collaboration formelle au début de 1988.

En ce qui concerne les activités STSP de l'ESA et de la NASA, une offre de participation conjointe a été lancée de 1er mars 1987 pour amorcer le processus d'offre et de sélection des charges utiles scientifiques. La sélection des charges utiles sera effectuée conjointement, et son achèvement est programmé pour fin 1987.

Les activités relatives à l'établissement d'un protocole d'accord ESA-NASA ont été mises en route, afin de parvenir à un accord d'ici octobre.

La rédaction de l'appel d'offres a également commencé, en préparation de la soumission, par l'industrie européenne, d'offres de fourniture en satellites. Il est prévu de lancer cet appel, qui comprendra la définition de la charge utile choisie, en février 1988.

Olympus

Les Revues critiques de la conception du sous-système de correction d'attitude et d'orbite (AOCS) d'Olympus et de l'ensemble de la charge utile, relatives aux quatre répéteurs et au système de détection des radiofréquences, ont maintenant été effectuées par le maître d'oeuvre. Suivant l'examen du sous-système de propulsion combinée, la revue critique de la conception du système aura lieu.

Les essais dynamiques du sous-système AOCS ont été terminés de manière satisfaisante dans l'installation NLR aux Pays-Bas, à l'aide du système qui avait été temporairement retiré du modèle d'identification du satellite. Ce dernier a ensuite été utilisé, après réintégration de l'AOCS, pour achever les essais électriques au niveau du système, ainsi que pour la mise au point du logiciel et des procédures d'essai du système intégré qui seront utilisés sur l'exemplaire de vol.

L'intégration et les essais du satellite de vol ont continué. L'expérience de propagation a été livrée au maître d'oeuvre de la charge utile, chez qui elle a été intégrée à ce qui constituera le panneau de communications orienté au Sud, ainsi que la charge utile de diffusion des programmes de télévision. Les deux panneaux de communications portant les quatre répéteurs de la charge utile seront livrés bientôt au maître d'oeuvre, une fois terminées les activités restantes d'intégration et d'essai. Le module de propulsion, avec le sous-système de propulsion combinée à bi-ergol installé, est presque terminé, sa livraison devant avoir lieu en mars. Entre-temps, l'intégration du module d'intervention et de l'étage supérieur du satellite s'est poursuivie dans la zone d'intégration principale du maître d'oeuvre, à mesure que les matériels de vol ayant subi des essais complets potential USSR provision of two more Cluster spacecraft, as a further cooperative effort within the STSP. To define the specific nature of this ESA/IKI collaboration, joint Working Groups have been established under the direction of a Joint Steering Committee. These will report to the ESA and IKI managements by the end of the year, leading to definition of the specific collaboration by early 1988.

As far as the ESA/NASA STSP activities are concerned, a joint Announcement of Opportunity was released on 1 March to initiate the scientific payload proposal and selection process. Payload selection will be performed jointly and is scheduled for completion by the end of the year.

Activities associated with establishing an ESA/NASA Memorandum of Understanding (MOU) have begun, with the intention of reaching agreement by October.

Drafting of the Invitation to Tender (ITT) has also been initiated, in preparation for securing spacecraft procurement proposals from European industry. It is planned to release this ITT, which will include the selected payload definition, in February 1988.

Olympus

The Critical Design Reviews for Olympus' Attitude and Orbit Control Subsystem (AOCS) and for the overall payload, covering the four repeaters and the radio-frequency sensing system, have now been conducted by the Prime Contractor. Following the combined Propulsion-Subsystem Review, the System Critical Design Review will be held.

Dynamic testing of the AOCS was completed satisfactorily at the NLR facility in The Netherlands using the system that had been temporarily removed from the engineering-model spacecraft. This spacecraft has subsequently been used, after re-integration of the AOCS, to complete the system-level electrical testing and for the development of the integrated system-test software and procedures that will be used on the flight model.

Integration and testing of the flight-model spacecraft has continued. The propagation payload was delivered to the main payload contractor where it was integrated onto what will be the south-facing communications panel, together with the television-broadcast payload. The two communications panels carrying the four payload repeaters will be delivered to the Prime Contractor soon, once the remaining integration and test activities have been completed. The propulsion module, with the bi-propellant combined propulsion subsystem installed, is nearly complete and is expected to be delivered during March. In the meantime, integration of both the service module and the top spacecraft floor has continued in the Prime Contractor's main integration area as fully tested flight equipment has become available. Acceptance testing of the solar-array wings has been satisfactorily completed.

Integration and testing of the flight spacecraft at system level will be completed when all the three modules are available. The spacecraft will then be prepared for environmental testing later this year, mainly at the David Florida Laboratories in Ottawa. The first test in this series will be a solar-simulation test at the NASA/Jet Propulsion Laboratory facility in California, the final preparations for which are already well advanced.

A revised interface control document has been agreed with Arianespace and issued.

ERS-1

Work is continuing on the structural-model programme, which is scheduled for completion in mid-1987. On the engineering model, schedule difficulties are being experienced with the delivery of some of the instruments. Ways and means of overcoming these delays are being investigated in conjunction with the Prime Contractor and every effort is being made to minimise any effect on the flight-model programme.

Turning to the ground segment, the Development Baseline Review for the Mission Management and Control Centre was held at the end of November 1986. The review highlighted those areas requiring attention and a plan of work defining the necessary activities and schedule milestones has been established. Activities related to the development of the Kiruna site have been defined with the Swedish Space Corporation, and it is planned that building will start in July this year.

Discussions with industry and Member States concerning the procurement of a second identical flight model, ERS-1, are continuing.

The response to the Agency's Announcement of Opportunity for the exploitation of ERS-1 data has been most encouraging. The large number of proposals received (about 300) has, however, meant that more time is needed for evaluation and selection.

Spacelab and IPS

For Spacelab, contract close-out activities are now firmly planned to be completed in the course of 1987. The last Data Display Unit has been repaired and formal re-acceptance testing is in progress. Disposal of residual Spacelab inventory items continues, with useful hardware being loaned or transferred to various interested parties.

On IPS, progress is being made in closing off items flagged during the formal Phase-C/D qualification and acceptance. Delivery of the Optical Sensor Package by the contractor is further delayed and awaits completion of the failure investigation and repair of the star-tracker assembly that failed during the Spacelab-2 mission, when the Igloo/Pallet/IPS-configuration was flown in July/August 1985.

Planning has been agreed between Dornier, ESA and NASA for installation and verification of a retro-fit kit for the gimbal latch mechanism, and for completion of remaining system-level acceptance tests with the Data Control Unit at NASA/KSC in March.

Follow-On Production

Support-services tasks for NASA/MSFC are being performed by ESA on a relatively small scale at NASA's request. The last FOP spares items to be delivered under the ESA/NASA FOP contract, the recently repaired IPS actuators, have been accepted and delivered.

devenaient disponibles. Les essais de recette des ailes du générateur solaire se sont terminés de manière satisfaisante.

L'intégration et les essais du satellite de vol au niveau du système seront terminés quand les trois modules seront tous disponibles. Un peu plus tard dans l'année. on préparera le satellite à des essais d'ambiance, principalement aux Laboratoires David Florida à Ottawa. Le premier essai de cette série sera un essai de simulation solaire dans les installations du Jet Propulsion Laboratory de la NASA en Californie, dont les derniers préparatifs sont déjà bien avancés.

Une version révisée du document de commande des interfaces a fait l'objet d'un accord avec Arianespace et a été publiée.

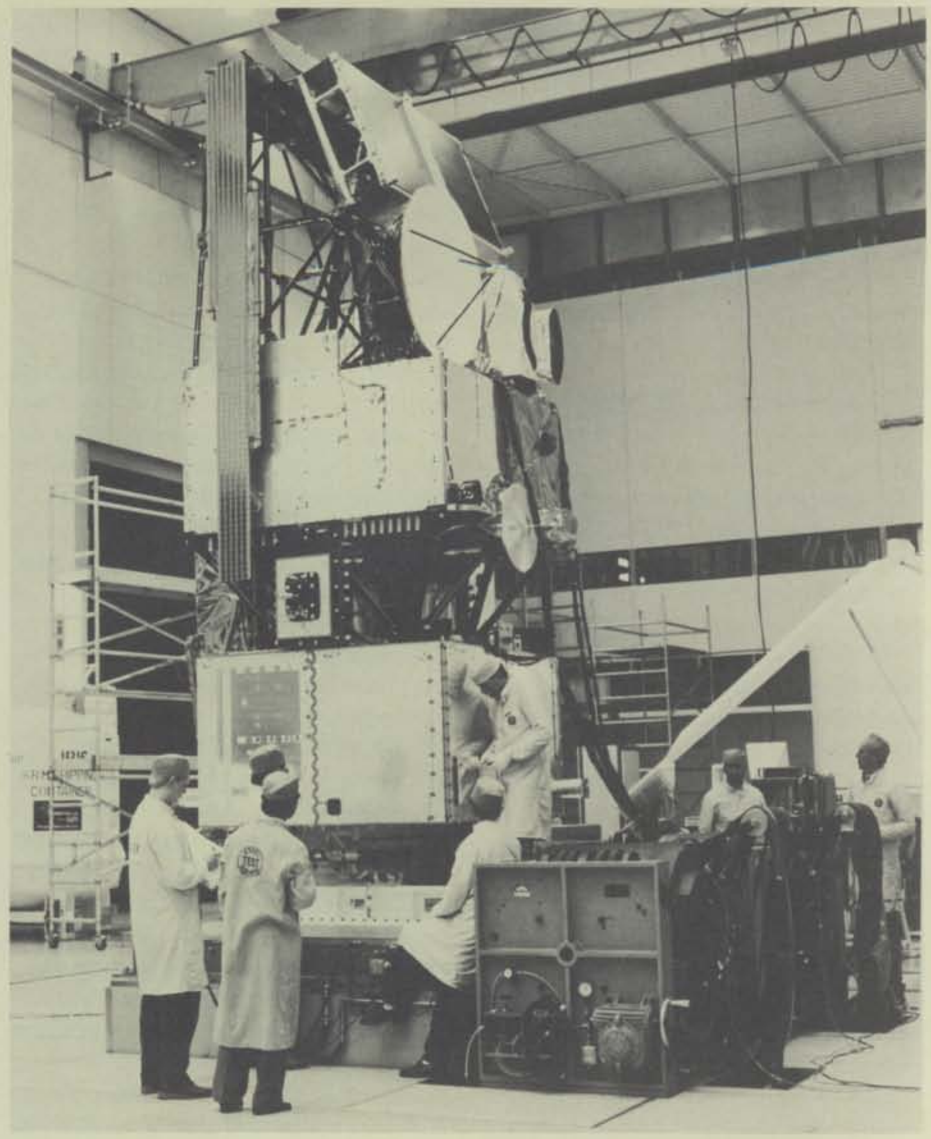
ERS-1

Les travaux se poursuivent sur le programme de modèle structurel, dont l'achèvement est prévu pour le milieu de 1987. Pour le modèle d'identification, on éprouve actuellement des difficultés concernant les délais de livraison de certains des instruments. On est en train d'étudier les différents moyens pour remédier à ces retards, avec le concours du maître d'oeuvre, et tous les efforts sont faits pour réduire au minimum toute répercussion sur le programme du modèle de vol.

Côté secteur terrien, l'examen des bases de référence du développement pour le Centre de gestion et de commande de la mission a eu lieu fin novembre 1986. Cette revue a mis en lumière les secteurs dans lesquels des problèmes restaient à résoudre, et un plan de travail définissant les activités nécessaires et les étapes du calendrier a été établi. Les activités relatives à la réalisation de la base de Kiruna ont été définies avec la Swedish Space Corporation, et, selon les prévisions, la construction commencera en juillet de cette année.

Les discussions avec l'industrie et les Etats membres concernant la fourniture d'un second modèle de vol identique, ERS-2, se poursuivent.

La réponse à l'offre de participation de l'Agence pour l'exploitation des données d'ERS-1 a été très encourageante. Vu le grand nombre d'offres reçues (300 environ), il faudra consacrer un certain temps à leur évaluation et à leur sélection.



ERS-1 engineering model undergoing vibration testing at ESTEC, Noordwijk

Modèle technologique d'ERS-1 pendant les essais de vibrations à l'ESTEC, Noordwijk

Spacelab et IPS

Pour Spacelab, la fin des activités de liquidation des contrats est maintenant définitivement arrêtée en 1987. La dernière unité d'affichage de données a été réparée, et les essais officiels de recette sont en bonne voie. On continue à se débarrasser des éléments restants du stock de Spacelab, le matériel utilisable étant prêté ou cédé à diverses parties intéressées.

En ce qui concerne le système de pointage des instruments (IPS), la liquidation des éléments signalés au cours de la qualification et de la recette de la phase C/D officielle est en bonne voie. La livraison de l'appareillage de détection optique par le contractant a encore été retardée, en attendant les résultats d'enquête et la réparation d'un ensemble de suiveur stellaire défaillant pendant la mission Spacelab-2 qui avait volé en configuration Igloo-Palette-IPS en juillet-août 1985.

Un calendrier a été convenu entre Dornier, l'ESA et la NASA pour l'installation et la vérification d'un 'kit' modifié après coup pour le mécanisme de verrou à la cardan, et pour l'achèvement, prévu en mars 1987, des essais restants de recette au niveau du système avec l'unité de commande de données au Centre Spatial Kennedy (KSC).

Space Station/ Columbus

Following completion of the Commonality Task Force's work in December 1986, the Reference Configurations for the Polar Platform (PPF) and the Man-Tended Free-Flyer (MTFF) were re-established, in line with the requirements changes introduced into the programme in order to baseline Hermes' servicing for the PPF. As anticipated, the introduction of the new requirements significantly influenced the level of commonality that could be expected between the PPF utilities module and the resource module of the MTFF. Consequently, the re-established baseline Reference Configurations were 'dedicated' configurations, with commonality achievable only at the subsystem level. It was decided, however, to continue with configuration options for both the PPF and MTFF, based on a common resource module and using the Shuttle as the servicing vehicle.

The final technical meeting of the ESA/NASA Joint MTFF Study was held at NASA/JSC during January and all unresolved points, both technical and operational, were finalised. The main conclusion of the study was that the proposed MTFF operational scenario falls within the envelope of the planned Space-Station operational capabilities and could, therefore, technically be accommodated. However, the NASA position with respect to including the MTFF as an integral part of the Space Station Cooperation is not yet finalised.

The Phase-B2 Mid-Term Review was completed during the week of 23 February at MBB/ERNO. The main objective of the Review, to verify the technical baseline to be costed for the coming Programmatics Review, was achieved.

Microgravity

The gap in flight opportunities after the Shuttle accident in January 1986 necessitated an overall review of the Microgravity Programme. An Interim Programme to bridge this gap is being prepared, in the form of an extension of Phase-2 activities. This extension is intended to give roughly equal priority to life and material/fluid sciences. To optimise the use of financial resources, the following guidelines are being applied:

- make maximum use of existing facilities, developed by ESA or national agencies;
- ensure repeated flights of the existing and new hardware in the frame of mini-missions through cooperation with national programmes (e.g. Texus, Maser, etc.);
- provide technical assistance and advice to experimenters.

Although the priorities for Shuttle-flight opportunities have not been settled, it now seems unlikely that the Sled will be flown before 1992. However, it might be possible to fly elements dedicated to vestibular research on the MIR Space Station in the framework of an ESA-Soviet cooperation.

For Biorack experiment coordination, interface meetings with investigators were started last December to prepare for all experiment acceptances. This activity will continue until the middle of the year, and is critical for establishing a sound basis for the subsequent crew training and mission preparations. The next working group meeting with NASA for the Shuttle IML-1 flight will be held in September.

A presentation was made in January by industry for the Preliminary Design Review of the Autonomous Fluid Physics Module. The provisionally selected investigators were present. Although good progress was made, a number of improvements have been proposed.

As far as sounding rockets are concerned, the Texus-14B/1S campaign is progressing satisfactorily and the double launch is foreseen for the second quarter of the year. Texus-16 is to be launched towards the end of the year.

At the time of writing, Maser-1 flight preparations are nearing completion, with launch scheduled for March. Preliminary ideas for the payload complement for Maser-2 are under discussion with the Swedish authorities.

A series of ESA-organised parabolic flights is scheduled for April, the main emphasis being on experimentation in combustion. Other experiments to be performed during these missions relate to solid-surface physics and life-sciences.

Eureca

Pending approval by the Columbus Programme Board, the development schedule for Eureca has been adjusted to a new launch date in May 1990.

The Payload Test Facility (PTF) required to verify the functional and physical interfaces between the Eureca spacecraft and its individual payload instruments is now assembled at ERNO in Bremen (Germany). The first interface tests between the PTF and the 'Multi-Furnace-Assembly (MFA)', one of the Eureca facility-type instruments, have been in progress since February.

The qualification programme for the Magnetic Bubble Memory has been completed successfully. Successful qualification of the primary structure of Eureca was reported earlier. The qualification programme for the remainder of the spacecraft's hardware and software is in full swing. Pending satisfactory results and feedback from this qualification programme, manufacture of the electronic flight hardware is planned to start towards the end of the year.

In parallel with the development activities on Eureca-1, which are mainly tailored to the needs of the microgravity user community, ESA undertook to study the adaptation of Eureca for astronomy missions. These studies were based largely on the needs of the Gamma-Ray Astronomy with Spectroscopy and Positioning (GRASP) instrument, one of several instruments proposed by the ESA Directorate of Scientific Programmes in the field of space astronomy. The GRASP study results have confirmed the feasibility of performing such a mission on Eureca, with the possibility of up to two years in orbit.

ESA has, in the meantime, approached NASA to book two more Eureca flights by paying the neccessary 'earnest money'.

Hermes

The Declaration for the start of the Hermes Preparatory Programme came into force at the end of November 1986. The management principle for this new ESA programme and the conditions of

Production ultérieure (FOP)

Des tâches relatives aux services d'assistance au Centre de Vols spatiaux Marshall (MSFC) sont actuellement assurées par l'ESA, sur demande de la NASA, à une échelle relativement modeste. Les derniers éléments de rechange à livrer dans le cadre du contrat de production ultérieur conclu entre les deux Agences, à savoir les actionneurs de l'IPS, récemment réparés, ont été acceptés et livrés.

Station spatiale/ Columbus

Suite à l'achèvement des travaux de 'l'équipe spéciale sur les eléments communs' en décembre, les configurations de référence pour la plate-forme méridienne (PPF) et le module autonome visitable (MTFF) ont été rétablies, en accord avec les modifications d'exigences introduites dans le programme afin d'établir les bases de référence de la desserte de la PPF par Hermès. Comme prévu, l'introduction de ces nouvelles exigences a eu une influence non négligeable sur le degré de similitude que l'on pouvait attendre entre le module de desserte de la PPF et le module de ressources du MTFF. Par voie de conséquence, les configurations de référence de base rétablies étaient des configurations 'spécialisées', la similitude ne pouvant être obtenue qu'au niveau des sous-systèmes. Il a toutefois été décidé de poursuivre l'étude des options de configuration aussi bien pour la PPF que pour le MTFF, sur la base d'un module de ressources commun et en utilisant la Navette comme véhicule d'intervention.

La dernière réunion technique relative à l'étude conjointe du MTFF s'est tenue au Centre spatial Johnson en janvier, et tout les points en suspens, sur les plans aussi bien technique qu'opérationnel, ont été résolus. La conclusion principale de l'étude était que le scénario opérationnel proposé pour le MTFF correspond bien aux capacités opérationnelles de la Station spatiale prévue et pourrait donc être accepté sur le plan technique. Cependant, la position de la NASA quant à l'inclusion de MTFF en tant que partie intégrante de la coopération à la Station spatiale n'est pas encore arrêtée définitivement.

La revue de milieu d'étude de la phase B2 s'est terminée dans la semaine du 23 février chez MBB/ERNO. L'objectif principal de cette revue, qui était de vérifier la base de référence technique dont il fallait évaluer le coût pour la revue des programmes à venir, a été atteint.

Microgravité

Les travaux ont avancé sur la phase 2 du programme de microgravité, une révision globale du programme ayant été rendue nécessaire par le manque d'occasions de vol dû à l'accident de la Navette en janvier 1986. Un programme intérimaire permettant de combler ce vide est en cours de préparation, sous la forme d'une extension des activités de la phase 2. On entend mettre ainsi sur le même pied d'égalité les sciences de la vie et les sciences des matériaux et des fluides. Pour utiliser au mieux les ressources financières, on a décidé d'appliquer les lignes directrices suivantes:

- *faire un usage maximal des installations existantes, réalisées par l'ESA ou par des agences nationales;*
- *assurer des vols répétés du matériel existant et nouveau dans le cadre de mini-missions, en coopération avec des programmes nationaux (Texus, Maser, etc.);*
- *fournir assistance et conseil techniques aux expérimentateurs.*

Bien que les priorités pour les occasions de vol de la Navette n'aient pas encore été fixées, il semble actuellement improbable que le 'Traîneau spatial' puisse être envoyé dans l'espace avant 1992. Cependant, on pourrait faire voler des éléments consacrés à la recherche vestibulaire à bord de la station spatiale MIR, dans le cadre d'une coopération ESA–URSS en sciences de la vie.

Pour la coordination des expériences de Biorack, des réunions d'interface avec les expérimentateurs ont commencé en décembre 1986 pour préparer l'ensemble des essais de recette des appareillages expérimentaux. Cette activité qui se poursuivra jusqu'au milieu de 1987, est cruciale pour l'établissement d'une base saine en vue de l'entraînement futur des astronautes et des préparatifs des missions. La prochaine réunion du groupe de travail avec la NASA pour le vol IML-1 de la Navette aura lieu en septembre.

Une présentation a été faite en janvier par l'industrie pour la revue de conception préliminaire du module autonome de physique des fluides en présence des expérimentateurs provisoirement sélectionnés. Bien qu'un grand progrès ait été enregistré, des améliorations ont été toutefois proposées.

En ce qui concerne les fusées-sondes, la campagne Texus-14B/15 se déroule de manière satisfaisante, et le double lancement est prévu pour le second trimestre de 1987. Texus-16 doit être lancé dans le courant du dernier trimestre de l'année.

Les préparatifs de vol de Maser-1 touchent actuellement à leur fin, le lancement étant prévu pour mars. Les premières idées relatives au complément de charge utile de Maser-2 sont en cours de discussion avec les autorités suédoises.

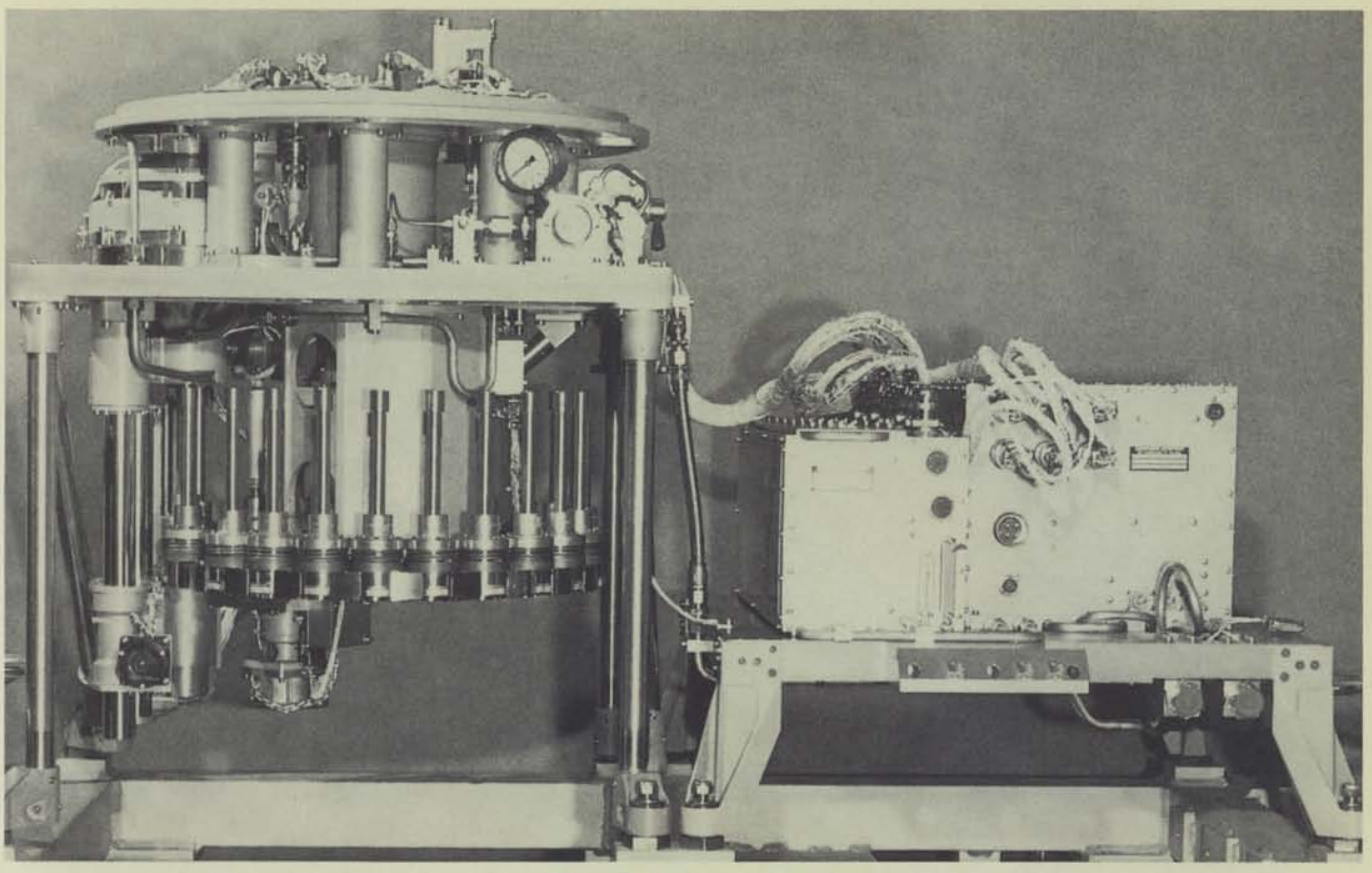
Une série de vols paraboliques organisés par l'ESA est prévue pour avril 1987, l'accent étant mis principalement sur des expériences de combustion. D'autres expériences sont également prévues sur la physique des surfaces solides et les sciences de la vie.

Eureca

Dans l'attente d'une approbation par le Conseil directeur du programme Columbus, le calendrier de réalisation d'Eureca a été ajusté à une nouvelle date de lancement en mai 1990.

L'installation d'essai de charge utile (PTF) qui est nécessaire pour la vérification des interfaces fonctionnelles et physiques entre la plate-forme Eureca et ses différents instruments de charge utile, est actuellement assemblée chez ERNO à Brême. Les premiers essais d'interface entre la PTF et 'l'ensemble multifour' (MFA), l'un des instruments du type installation à embarquer sur Eureca, se déroulent depuis février 1987.

Le programme de qualification de la mémoire à bulles magnétiques a été mené à bonne fin. La qualification de la structure primaire d'Eureca a fait l'objet d'un rapport antérieur. Le programme de qualification du reste du matériel et du logiciel de l'engin spatial bat son plein. Dans l'attente de résultats satisfaisants et



delegation to CNES have been negotiated and detailed in a formal ESA-CNES Agreement, which was approved by the ESA Council in March.

Continuation of the CNES-managed industrial activities was approved for the Prime Contractors at the end of last year. Detailed negotiations and tender evaluations are now taking place in preparation for the release of subsystem and equipment work.

The detailed system definition of the spaceplane configuration selected by CNES in July 1986 resulted in the reassessment of several important design choices, particularly in the areas of structure, thermal protection, propulsion and crew support. The analysis of crew-safety requirements led to improved escape and rescue scenarios being investigated. Both activities led to an increase in the estimated mass of the basic spaceplane. They also confirmed the need to increase the design margin to cope with technological uncertainties and with the new crew-safety requirements.

The problem created by this mass increase was tackled from three sides. First, mass-reduction measures, including a reduction in the overall fuselage size, will be applied to Hermes, with the aim of reducing the basic spaceplane mass to 13.9 t.

Secondly an analysis of the servicing mission has shown that a considerable saving in gross payload transported for the Man-Tended Free-Flyer (MTFF) servicing scenario could be achieved by replacing the open cargo bay with a pressurised one. The savings would come essentially from the deletion of a pressurised logistic module, and from a new refuelling concept. These measures maintain essentially the same net payload, equipment and fuel transport capability, but they necessitate review of the MTFF servicing scenario. The servicing of the Polar Platform by Hermes is also compromised under the present mass constraints.

The third component of the corrective actions undertaken by ESA, in close consultation with CNES, has been the definition of an upgraded version of Ariane-5. The change in size of both the solid boosters (from a P190 to a P230 version) and of the cryogenic stage (from H140 to H155) will produce a payload-mass increase in low Earth orbit from 18.6 to 21 t. One major consideration in this new choice was the need to maintain the commercial competitiveness of Ariane for automatic launches, particularly for the geostationary transfer orbit.

Le four à miroir automatique destiné à Eureca

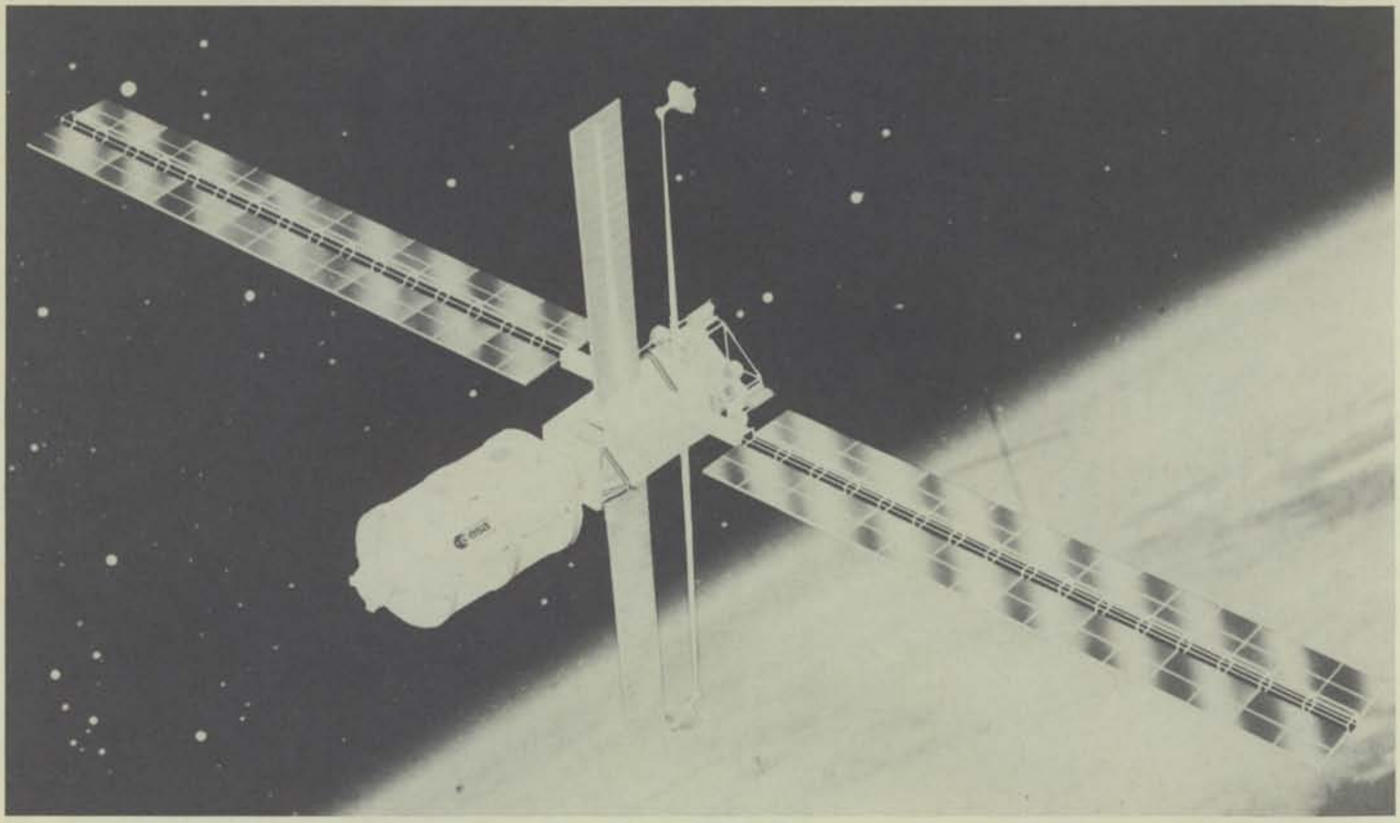
The Eureca Automatic Mirror Furnace (AMF)

The Director General has appointed a Task Force to examine the implications and coherence of the above preliminary baseline assumptions.

Ariane

Following the loss of Ariane V18, the short-term plan of action leading to the resumption of Ariane launches bears mainly on the following three areas:
- combustion chamber ignition
- gas generator ignition
- cooling and lubrication of the rear turbine bearing and the immersed hydrogen pump bearing.

The modifications that are to form part of the new flight standard have now been



Artist's impression of the Man-Tended Free-Flyer (MTFF)

Vue imaginaire du module autonome visitable (MTFF)

des retours de ce programme de qualificattion, le début de la fabrication du matériel électronique de vol est programmé pour fin 1987.

Parallèlement aux activités de réalisation d'Eureca-1, qui sont surtout ajustées aux besoins de la communauté des utilisateurs de la microgravité, l'ESA a entrepris d'étudier l'adaptation d'Eureca à des missions d'astronomie. Ces études étaient basées dans une large mesure sur les besoins de l'instrument d''Astronomie en rayons gamme avec spectroscopie et positionnement' (GRASP), qui fait partie des instruments proposés par la Direction des programmes scientifiques dans le domaine de l'astronomie spatiale. Les résultats des études GRASP ont confirmé qu'une telle mission sur Eureca était faisable, avec possibilité de passer jusqu'à deux ans en orbite.

Dans l'intervalle, l'ESA a pris contact avec la NASA pour réserver un plus grand nombre de vols d'Eureca en versant le dépôt de garantie nécessaire.

Hermès

La déclaration relative au démarrage du programme préparatoire Hermès est entrée en vigueur fin novembre. Le principe de gestion de ce nouveau programme de l'ESA, ainsi que les conditions de sa délégation au CNES, ont été négociés et détaillés dans un accord officiel ESA-CNES, qui a été approuvé par le Conseil de l'ESA en mars 1987.

La poursuite des activités industrielles gérées par le CNES a été approuvée pour les maîtres d'oeuvre à la fin de 1986. Des négociations détaillées et des évaluations d'offres ont actuellement lieu en préparation du lancement des travaux relatifs aux sous-systèmes et aux matériels.

La définition détaillée au niveau système de la configuration de l'avion spatial retenue par le CNES en juillet 1986 a abouti à la réévaluation de plusieurs choix de conception importants, notamment dans les secteurs de la structure, de la protection thermique, de la propulsion et de la prise en charge des astronautes. L'analyse des exigences relatives à la sécurité de l'équipage a conduit à envisager des scénarios améliorés pour la sécurité et le sauvetage. Les deux activités se sont traduites par une augmentation de la masse estimée de l'avion spatial de base. Elles ont également confirmé la nécessité d'accroître la marge de conception pour faire face à des incertitudes technologiques et aux nouvelles exigences de sécurité des équipages.

Le problème posé par cette augmentation de masse a été attaqué de trois côtés. Premièrement, des mesures de réduction de la masse, comprenant une réduction des dimensions globales du fuselage, seront appliquées à Hermès, dans le but de réduire la masse de l'avion spatial de base à 13,9 t.

Deuxièmement, une analyse de la mission d'intervention a démontré que l'on pourrait réaliser des économies considérables sur la charge utile brute transportée pour le scénario d'intervention du MTFF (Module autonome visitable) en remplaçant le compartiment à cargaison ouvert par un compartiment pressurisé. Ces économies résulteraient essentiellement de la suppression d'un module logistique pressurisé, et d'une nouvelle méthode de réapprovisionnement en ergols. Ces mesures permettent de conserver sensiblement la même charge utile nette, les mêmes équipements et la même capacité d'emport d'ergols, mais elles nécessitent une révision du scénario finalised, except in the case of the immersed bearing. The technical difficulties encountered in this area have delayed availability of the engine assigned to flight 19.

Combustion chamber ignition
The new ignition configuration has been finalised on the basis of a series of 32 altitude-simulation tests (on the SEP/PF41 test stand) on a first engine (August to December 1986). The main modification is an improvement to the pyrotechnic igniter: power has been trebled and the gases enter the combustion chamber as two jets angled at 45°. Compared with the old (axial jet) configuration, this modification achieves gentler ignition thanks to improved mixing of the gas jets and the oxygen and hydrogen jets. The ignition delay has been reduced appreciably (typically 40 ms as against a previous minimum of 100 ms) and pressure peaks occurring in the LH_2/LOX feed circuits on ignition have been eliminated.

The new-type of igniter has successfully undergone a qualification programme of 25 hot tests following environmental tests. The margin appraisal and qualification campaign for the new ignition configuration began in mid-April on a second test engine. It consists of an initial series of about 10 tests required for authorisation of the next launch.

Gas generator ignition
The modification entails an adjustment to the opening sequence of the LOX and LH_2 injection valves in order to minimise the pressure peak that occurred on earlier flights upon ignition. The new sequence adopted (LH_2 valve opening command advanced by 50 ms) was finalised in the course of a campaign of 13 tests carried out on a third engine.

Cooling and lubrication of turbopump bearings
The additional development work was carried out in parallel with the work on chamber and generator ignition.

In the case of the rear turbine bearing, numerous development tests were performed on turbopumps, first 'cold' (turbine driven by gaseous hydrogen) and then 'hot' (PF41 test stand). The modification adopted, which proved very effective in correcting the previous overheating of the bearing, entails a further injection of a mixture of gaseous hydrogen and tributylphosphate.

With regard to the immersed hydrogen pump bearing, the initial development tests were performed on pumps both in isolation and mounted on the engine. The modification entails increasing the flow of coolant hydrogen through the bearing (widening the cross-section through the injection aperture filters).

The setting adopted following these tests did not prove efficient enough in the first acceptance test (January 1987) carried out on the engine initially assigned to flight 19. Further development difficulties that appeared in the course of later tests necessitated additional work to improve the behaviour of the bearing.

The further improvement now being tested involves lubricating the bearing bush with molybdenum disulphide in order to improve its performance under axial forces. The flight 19 engine should therefore be available in mid-June.

Date of flight 19
Final acceptance of the engine is necessary prior to finalisation of the date for flight 19 and the schedule for subsequent launches. The mid-June engine availability date indicated above implies an August 1987 launch.

d'intervention du MTFF. La desserte de la plate-forme méridienne par Hermès est, elle aussi, compromise en l'état actuel des contraintes de masse.

La troisième composante des mesures correctrices prises par l'ESA, en concertation étroite avec le CNES, a été la définition d'une version plus puissante d'Ariane-5. L'augmentation de la taille des propulseurs à poudre (de 190 t à 230 t) d'une part, et de l'étage cryogénique (de 140 t à 155 t), d'autre part, permettra d'obtenir une augmentation de la masse de la charge utile, en orbite basse, de 18,6 t à 21 t. Un facteur majeur de ce nouveau choix était la nécessité de conserver la compétitivité commerciale d'Ariane pour les lancements automatiques, notamment pour l'orbite de transfert géostationnaire.

Le Directeur général a créé une 'équipe spéciale' pour examiner les implications et la cohérence des hypothèses de référence ci-dessus.

Ariane

Le plan d'action à court terme en vue de la reprise des vols Ariane porte principalement sur les trois domaines suivants:
- *allumage de la chambre de combustion*
- *allumage du générateur de gaz*
- *refroidissement et lubrification du roulement 'arrière' de la turbine et du roulement 'noyé' de la pompe hydrogène.*

Les modifications destinées à faire partie du nouveau standard de vol sont maintenant établies, mises à part celles concernant ce dernier roulement; les difficultés techniques rencontrées dans ce domaine ont retardé la disponibilité du moteur affecté au vol 19.

Allumage de la chambre de combustion
La nouvelle configuration d'allumage a été mise au point à partir d'une série de 32 essais effectués en condition d'altitude simulée (banc SEP/PF41) sur un premier moteur (août à décembre 86). La principale modification concerne l'amélioration de l'allumeur pyrotechnique dont la puissance est triplée et dont les gaz débouchent dans la chambre de combustion en deux jets déviés à 45°. Par rapport à l'ancienne configuration (jet axial), cette modification permet un allumage doux grâce à un meilleur mélange entre les jets de gaz et les jets d'oxygène et d'hydrogène: le retard à l'allumage est notablement réduit (40 ms contre 100 ms minimum auparavant) et les surpressions à l'allumage dans les circuits d'alimentation LOX/LH_2 sont supprimées.

Le nouveau type d'allumeur a été soumis avec succès à un programme de qualification ayant comporté 25 mises à feu après épreuves d'environnement. La campagne d'évaluation de marge et de qualification de la nouvelle configuration d'allumage a débuté mi-avril sur un deuxième moteur d'essai; elle comporte une première série d'environ 10 essais nécessaires pour autoriser le prochain vol.

Allumage du générateur de gaz
La modification consiste en un ajustement de la séquence d'ouverture des vannes d'injection LOX et LH_2 du générateur pour minimiser la surpression à l'allumage constatée lors de vols antérieurs. La nouvelle séquence retenue (avance de 50 ms de la commande d'ouverture de la vanne LH_2) a été mise au point au cours d'une campagne de 13 essais effectués sur un troisième moteur.

Refroidissement et lubrification des roulements de la turbopompe
Les travaux complémentaires de développement ont été effectués en parallèle avec ceux concernant l'allumage de la chambre et du générateur.

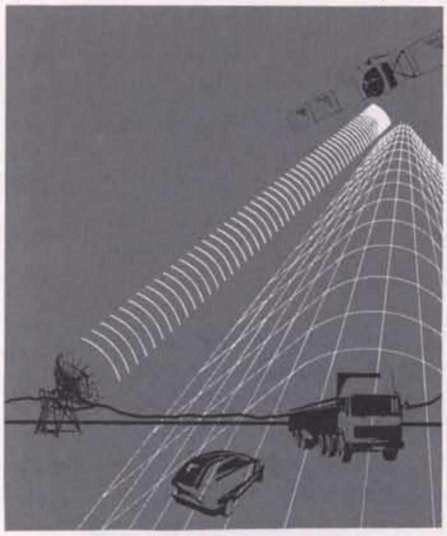
En ce qui concerne le roulement arrière de la turbine, de nombreux essais de mise au point ont été effectués sur turbopompes, d'abord en essais à 'froid' (entraînement de la turbine par hydrogène gazeux) puis en essais à feu (banc PF41). La modification retenue s'est avérée très efficace pour remédier aux échauffements anormaux constatés auparavant sur le roulement; elle consiste en une injection supplémentaire d'un mélange d'hydrogène gazeux et de tributylphosphate.

En ce qui concerne le roulement 'noyé' de la pompe hydrogène, les essais initiaux de mise au point ont été effectués sur pompes seules et sur moteur. La modification établie a consisté à augmenter le débit d'hydrogène de refroidissement passant au-travers du roulement (augmentation des sections de passage des filtres situés sur les orifices d'injection).

Le réglage retenu à l'issue de ces essais ne s'est pas avéré suffisamment efficace lors du premier essai de recette du moteur initialement affecté au vol 19 (janvier 87). Les difficultés supplémentaires de mise au point qui sont apparues au cours d'essais ultérieurs ont demandé des travaux complémentaires pour améliorer le fonctionnement de ce roulement.

La nouvelle amélioration actuellement essayée consite à lubrifier, au bisulfure de molybdène, le palier de roulement pour permettre un meilleur coulissement de ce dernier en sollicitation axiale. Le moteur du vol 19 devrait alors être disponible mi-juin.

Date du vol 19
La recette finale du moteur est attendue pour fixer définitivement la date du vol 19 ainsi que le calendrier des autres lancements; la date de disponibilité du moteur indiquée ci-dessus conduit à un lancement courant août 1987.



ARAMIS: An Advanced Payload Concept for the Mobile Satellite Service

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Satellite mobile communications will continue to expand in both scope and scale in the coming years, increasing the pressures on spectrum resources and space-segment capacity, and leading to a requirement for the use of spot beams. This in turn requires that suitable satellite payload technology be developed.

ARAMIS is an ESA programme conceived to define the characteristics of such a payload, to identify the technology developments required, and to design and build the payload itself. This programme will enable European industry to develop the technology needed for the future and thus bid successfully for future operational systems.

Introduction

Satellite communication for merchant shipping became a reality in 1976 with the launch of the first Marisat satellite, which provided an initial communications capacity at L-band frequencies (1.5 /1.6 GHz). This satellite's launch was a substantial factor in the international discussions and negotiations that led to the setting-up of the pre-INMARSAT Joint Venture. The latter prepared the way for the establishment of INMARSAT, the international entity now charged with the provision of satellite-communications services to the maritime community and possibly, in the future, with aeronautical satellite communication services also.

These first satellites provided a nominal capacity of ten voice telephony channels. It was realised however that, as soon as maritime satellite communications became established, the growth in traffic would be such that a much larger in-orbit capacity would be needed. Having recognised this, ESA financed the development of the Marecs mobile communications satellite using the ECS satellite bus. Two Marecs satellites, launched in 1981 and 1984, are now an indispensable part of the INMARSAT 'first-generation' space segment.

In 1983, INMARSAT commenced procurement of spacecraft for their second-generation space segment. Their communications payloads will be more or less identical to those of the first generation, though offering a much increased capacity. The first of these spacecraft will come into operational use towards the end of the decade.

Maritime mobile satellite communications have already become well established for that part of the maritime community using vessels large enough to carry the large (≥80 cm diameter), high-gain directionally stabilised antennas required. However, future developments will tend towards the provision of services to mobiles capable of carrying only small, nondirectional — and hence low-gain — antennas (small craft and aircraft). This in turn will require higher Equivalent Isotropically Radiated Powers (EIRP's) from spacecraft, and a higher gain from the spacecraft antenna.

The increase in traffic accompanying the increase in the size of the user community will also require an increase in the capacity of the space segment, underlining the need for efficient use of the somewhat limited frequency-spectrum resources available.

These are all prime factors in the definition of the third generation of mobile-communications spacecraft, the first elements of which are expected to be commissioned before the mid-1990s.

Characteristics of third-generation payloads

Spot beams

Certain reasonable assumptions can be made about the ground segment, and specifically the characteristics of the mobile terminals, needed for a third generation of module communications. For instance, it can be assumed that the low-data-rate terminals will operate at about 500 bit/s, whereas voice will be transmitted at either 4.8 or

9.6 kbit/s with efficient vocoders. The transmit power will be between 10 and 15 W, and the antenna gain either 0 dBi, or 10 to 12 dBi. These factors combine to require a substantially higher spacecraft L-band antenna gain for the return link than can be achieved using a global beam of the Marecs type.

Instead, a pattern of high-gain spot beams is needed to provide global coverage (Fig. 3). Given also the somewhat limited L-band spectrum resources allocated to mobile services, it will be necessary to re-use the same channel frequencies in two or more spot beams that are sufficiently separated geographically for this to be realistic. This will greatly increase the traffic-carrying potential of the satellite.

Global beams

The INMARSAT 'Standard-A' mobile terminals currently in use cannot be operated in a spot-beam system. Other standards, yet to be introduced, will include this capability. It is anticipated that several thousand Standard-A terminals will still be in service when the first of the third-generation satellites is commissioned. INMARSAT will therefore be committed to continue servicing them for most of the lifetime of the third generation, with demand falling gradually during this period. In the same period, spot-beam traffic will be building up and the payload design should therefore allow for this gradual transition in required resources.

Flexibility of resources

The first of the third-generation satellites is expected to enter service around 1995. It is difficult to forecast just what percentage of the total traffic will be served by the various standards of terminal at that time. Nor is it possible to venture more than an informed guess as to what the geographical distribution of the traffic will be. Also, it may be necessary periodically to move spacecraft from one region to another with different traffic levels and distributions. To use the available resources optimally, therefore, a high degree of flexibility in reallocating traffic volumes and types between beams is mandatory.

Third-generation payloads

A multiple-reflector antenna system is the easiest means of generating several noncontiguous beams. However, practical constraints, imposed by the dimensions of the satellite platform and launcher shrouds, preclude this solution when more than three or four beams are needed.

A focusing concept, with a single reflector and a cluster of signal feeds in its focal plane, is a more interesting alternative. The disadvantage is that a Beam-Forming Network (BFN) is necessary in this case between each power amplifier and the feeds. A beam is then no longer associated with a particular feed, but rather with a particular power amplifier (in the forward link) and the total power is split between all beams, in accordance with their traffic. If the traffic is expected to change, therefore, each beam amplifier has to be sized for the maximum expected traffic.

Most of the time, the traffic will be less than this maximum and the power amplifier will be operating at less than optimum efficiency. This imposes a heavy penalty on the satellite power system. Unfortunately, a 'constant-efficiency' amplifier, which would avoid this shortcoming, does not yet exist.

Studies carried out at ESTEC indicate that the focusing concept is attractive when five to seven contiguous beams are

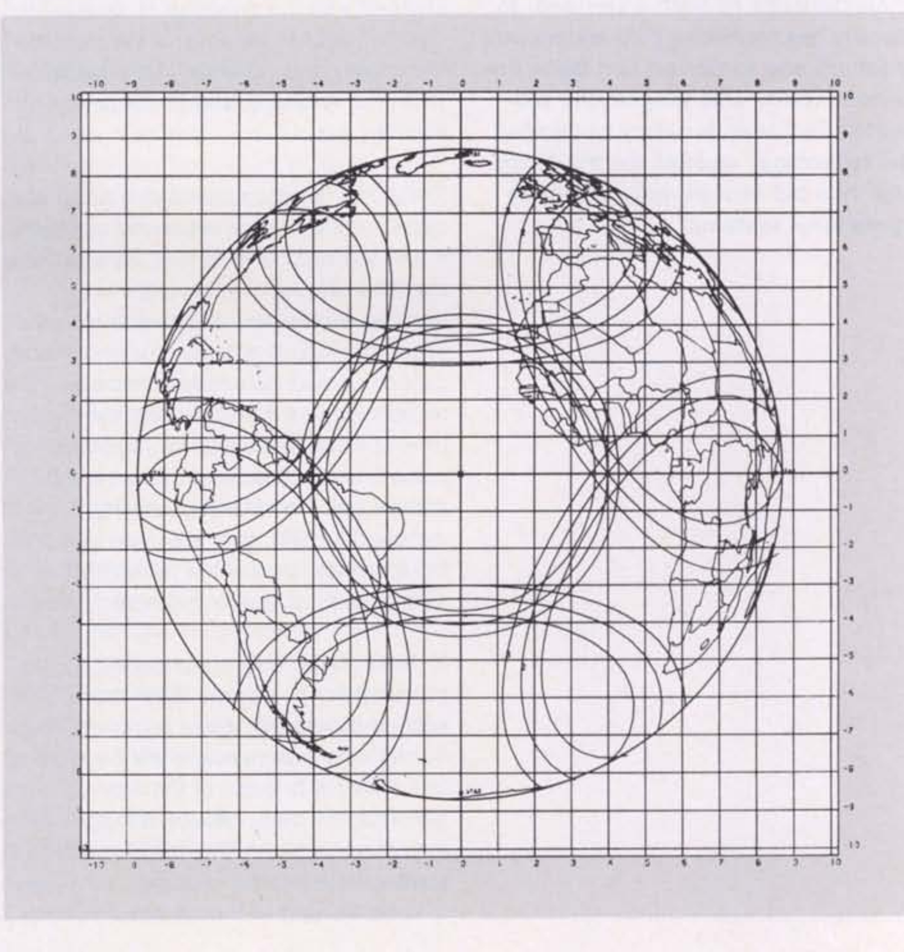


Figure 1 — Earth coverage with seven elliptical beams, achieved with seven feeds combined two by two (isogain contours at 21, 22 and 23 dBi)

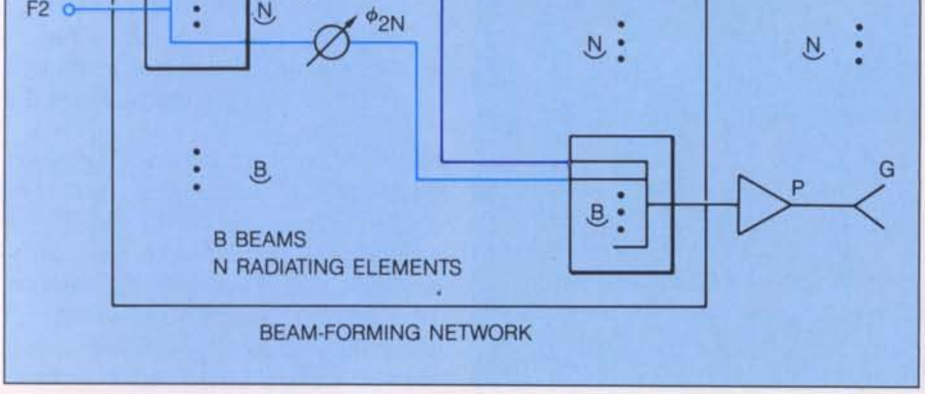


Figure 2 — Schematic of a direct-radiating phased array

needed. Figure 1 shows a typical Earth coverage with seven elliptical beams, achieved with seven feeds combined two by two. Proper excitation of the seven feeds could also provide the global beam necessary for the existing INMARSAT Standard-A service.

A direct-radiating phased-array concept is an elegant means of overcoming many of the above limitations. The cross-over gain can be as high as necessary and the EIRP in the beams can be modified without changing the overall payload efficiency. The principles of the technique are illustrated in Figure 2. A signal F1 enters a Beam-Forming Network where it is split into N identical parts. A dedicated phase shift is then applied to each of these coherent subsignals. N identical elements (either a power amplifier in the forward link, or a receiver in the return link) connect the BFN to the N identical radiating elements. In space the N (sub)signals at frequency F1 combine and, if the set of phase shifts has been properly calculated, converge in a certain direction, which is directly related to this set. If variable phase-shifters are used, it is possible to control the beam's direction from the ground.

Taking into account the likely requirements for a third-generation mobile satellite service, and in particular the need for operating flexibility and a launch date in the early 1990s, the direct-radiating-array concept seems the most appropriate and has been retained for the ARAMIS payload.

Typical ARAMIS payload

Although the mission and system requirements for the next generation of aeronautical and maritime services are not yet firmly established, reasonable assumptions can nevertheless be made. In particular:

- Mobile earth stations will have the INMARSAT-specified performance for the service in the global (Standard-A or B), or spot (Standard-B) beams, a radiated power (EIRP) of 15 to 20 dBW, and a figure-of-merit (G/T) of −17 to −24 dB/K for a typical spot-beam-only service.
- The radio-frequency operation will be at L-band in the mobile link (around 1.55 GHz forward link, 1.65 GHz return) and C-band in the feeder links (6.6 GHz forward / 3.6 GHz return).
- A total L-band EIRP of at least 36 to 39 dBW in the global beam, and about 45 dBW in the spot beams, is desirable.
- For a satellite over the Atlantic Ocean, some L-band frequency spectrum should be reused, at least between two zones, one covering Europe and the other the east coast of the USA.

At L-band, a single antenna can be used to generate, transmit and receive a global beam and, typically, 12 fixed spot beams, with the necessary gain. In addition it can also generate two movable beams with the same characteristics as the fixed beams. Figure 3 shows the Earth coverage that can be achieved. In this case, the antenna consists of 25 elements, each of which is an aggregate of low-gain patches. It fits comfortably inside a circle of 1.9 m diameter.

The payload block-diagram is presented in Figure 4. The RF power in the elements is rather low (less than 40 W) so that multipaction and passive intermodulation will not occur. A diplexer separates the transmit and receive signals associated with each antenna element.

In the forward link, the signals are received at C-band. They are then amplified and downconverted at a much lower intermediate frequency before they enter the IF Processor. This unit, where the necessary flexibility in traffic-to-beam allocation is implemented, slices the overall received spectrum into strips of smaller bandwidths (surface-acoustic-wave or digital filters) and connects them, on ground command, to the various beams.

In the return link, the block-diagram is a mirror-image of the forward link: 25 coherent receive chains connect the diplexers to the receive BFNs, operating also at intermediate frequency. The return

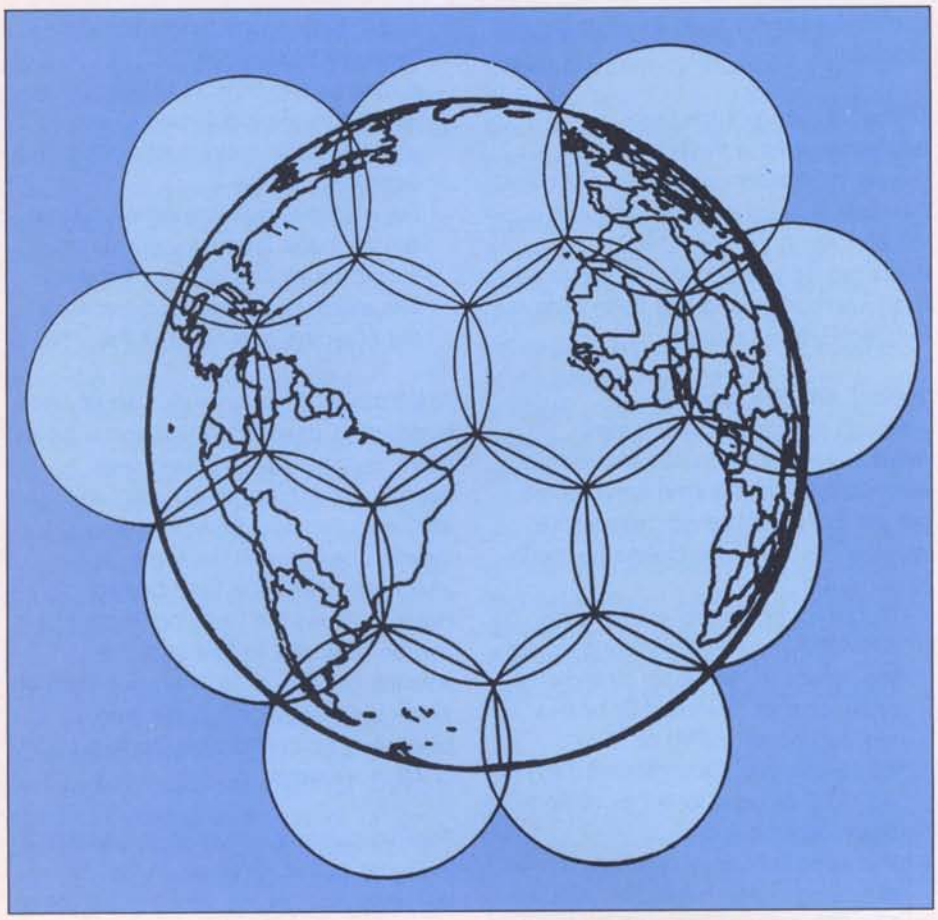


Figure 3 — Typical ARAMIS coverage

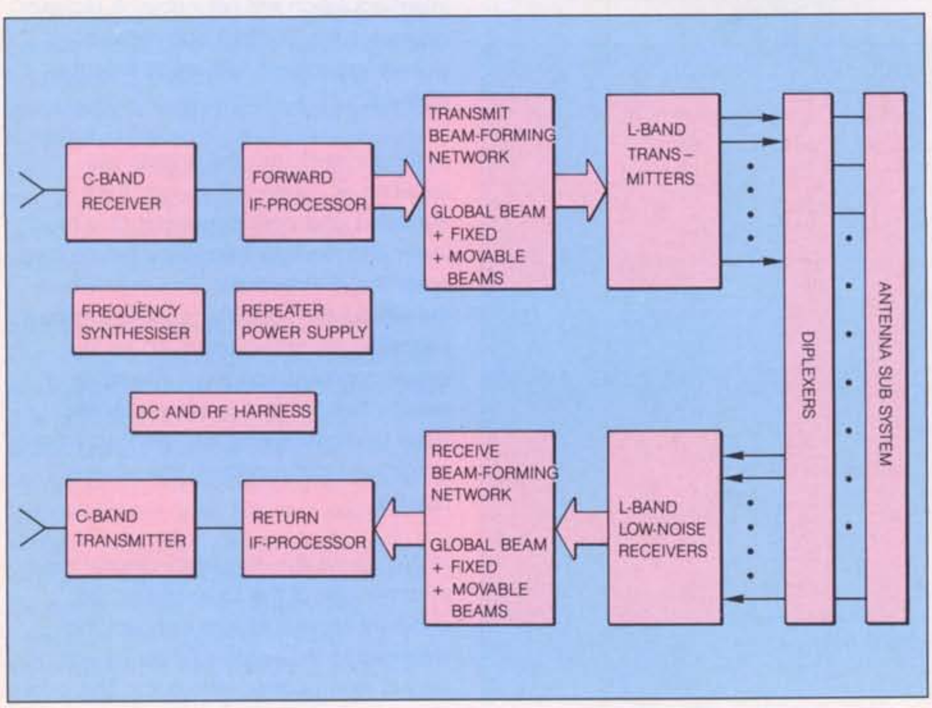


Figure 4 — ARAMIS payload block diagram

IF Processor assembles the signals from all the beams and interfaces with the return upconverter, which translates them to C-band for transmission to the ground.

Critical payload hardware
Although ARAMIS is an advanced concept that has not yet flown, its technology is well-defined and has been the subject of many development contracts in recent years.

The overall size of the L-band antenna has been limited to less than 2.5 m, in order to be able to install it on the Earth-pointing face of the platform without deployment. Two types of radiating elements have been considered:

— The Short Back-Fire (SBF), developed extensively by ERS (Sweden) is close to qualification level. It consists of a crossed-dipole feed in a cylindrical cavity (Fig. 5) about 43 cm in diameter. A peak gain of some 15 dB can be achieved, with as much as 14 dB within the Earth-coverage zone. Use of Carbon-Fibre-Reinforced Plastic (CFRP) material leads to a lightweight overall assembly. A typical configuration with 19 elements would weigh about 16 kg.

— The Microstrip Patch is a low-gain circularly polarised element about 8.5 cm in diameter and with a gain of about 7.5 dB. These elements seem less performant at first sight than the SBF, but when assembled in subarrays they make it possible to control the overall antenna excitation better and thereby lead to better performance than provided by the SBF. A representative configuration, with 19 patches is shown in Figure 6.

An antenna with 121 individual patches distributed in a hexagonal grid, and coupled to constitute 25 radiating elements (subarrays), has been evaluated. Its overall diameter is less than 1.9 m and it is capable of generating (transmit and receive modes) the 12-beam configuration of Figure 3, with a

Figure 5 — Short back-fire antenna element

Figure 6 — 19-patch-element L-band antenna

Figure 7 — L-band 20 W power-amplifier module

minimum edge or coverage gain of 23 dBi, together with a global beam with a gain of 18 dBi. The sidelobe levels are such that a minimum isolation of 20 dB is achieved for frequency-reuse purposes.

The Aramis L-band front end requires output powers between 10 and 40 W. The L-band power amplification is achieved with bipolar technology. The amplifiers, developed by Marconi (UK), feature a novel Dynamic Electronic Bias Scheme (DEBS), which has the advantage of constant gain and improved efficiency over a wide dynamic range. A 20 W ARAMIS module is shown in Figure 7.

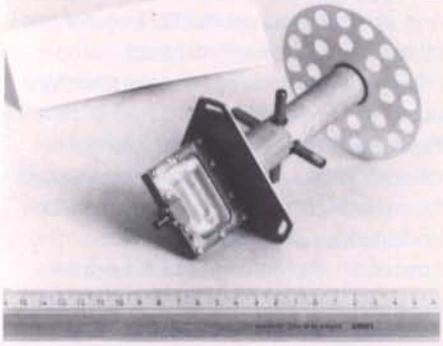
Another critical element of the ARAMIS payload is the L-band receiver, which has been studied extensively by Marconi. The main features of this unit are its very low noise figure (1.5 dB) and its extreme lightness (less than 200 g). This has been achieved by using low-loss microwave techniques and state-of-the-art lightweight technology.

A major feature of ARAMIS is the possibility of onboard channel-to-beam reconfiguration, provided by the IF Processor and the channel-to-beam switching matrix. The former can be implemented using a combination of surface-acoustic-wave and digital-filtering techniques in order to use the frequency-spectrum resources efficiently and achieve the required flexibility.

The Beam-Forming Network in the forward and return link transponders can be implemented at IF using standard UHF techniques or at L-band using high-permittivity substrates that would reduce the size of the unit.

Conclusion

The third-generation mobile satellite service is going to impose heavy demands on the payload; higher gain and higher radiated powers (EIRPs) will have to be provided. Spot beams will have to be generated with low cross-over levels and traffic will have to be allocated dynamically to beams. The limited frequency spectrum at L-band has to be re-used in the various beams. ARAMIS is a concept that fulfils all of these requirements. Moreover, the technology is mature enough for a launch in the early 1990s to be pursued with confidence.



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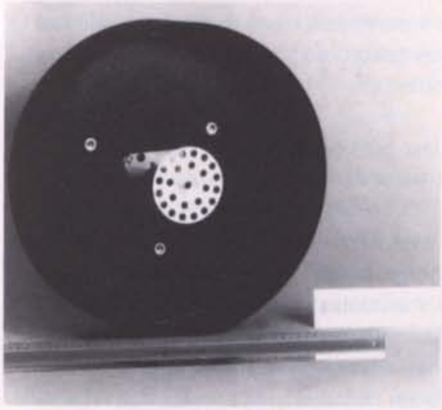

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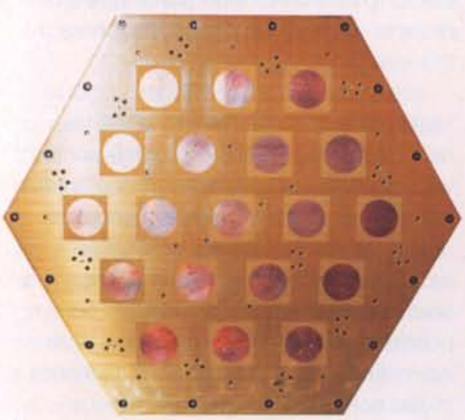

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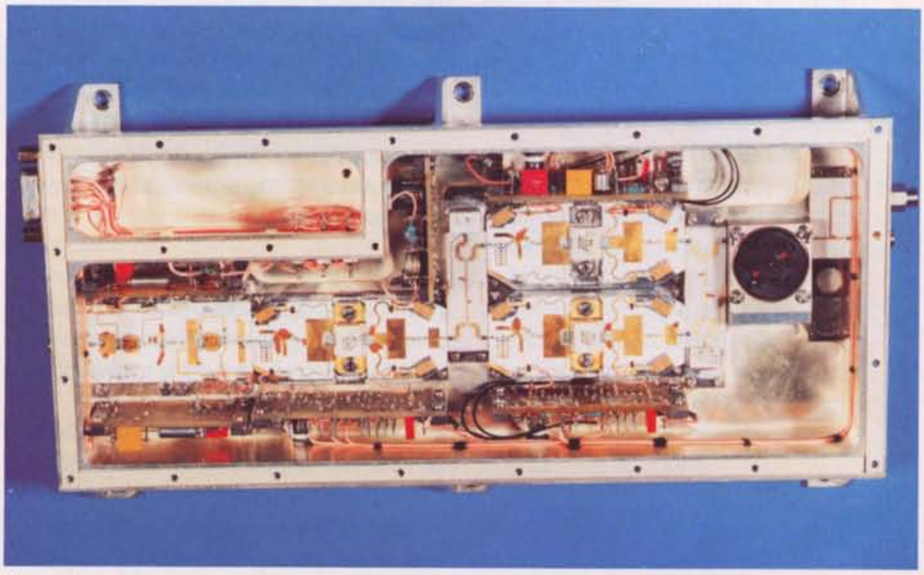

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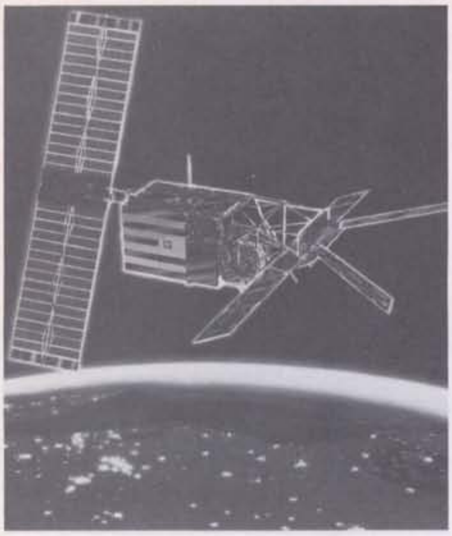

Precise Orbit Determination at ESOC

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A four-year development programme is currently underway at ESOC to support those future ESA near-Earth missions that have stringent orbit-accuracy requirements. The activity is centred around an ESOC-developed software system for orbit determination and error analysis which contains state-of-the-art models for a wide range of orbital perturbations and measurement types. It permits estimation and error analysis of geophysical and geodetic parameters in addition to the orbital states of the satellites.

Introduction

With the advent of a new generation of spacecraft for studying the Earth's surface and interior, more and more stringent requirements are being placed on the precision with which the position and velocity of the spacecraft have to be computed. Radial-position accuracy of better than 10 cm and along-track accuracy of better than 50 cm are typical of the orders of magnitude required of radar altimetry for the determination of global ocean circulation and for study of the dynamics of the Earth and its crustal movements by means of satellite tracking.

To ensure that adequate support for such missions can be provided by the Agency's Operations Centre in Darmstadt, a four-year programme has been initiated with the aim of upgrading available in-house software and expertise. Already, approximately two years into this programme, significant results can be reported. In particular, it has been possible by participation in an international data-reduction campaign to compare objectively the capabilities of our software, and the geodetic and geophysical results obtained, with those of other centres.

Objectives of the programme

The Precise Orbit Determination programme for near-Earth orbiters is a natural extension and continuation of many years of orbit-determination activities at ESOC. Beginning with the early ESRO satellites in the late 1960s which were tracked by just a few stations yielding inaccurate direction measurements, routine orbit determination has been carried out for five near-Earth satellites (1969—1974), for ten spacecraft in geostationary-transfer and synchronous orbits (1977—), for five highly eccentric Earth orbiters (1969—1986), and for two interplanetary orbits (a spacecraft, Giotto, and a comet, Halley, in 1986). The results of these determinations have not only been used for mission-control purposes (e.g. station and manoeuvre scheduling, and spacecraft monitoring), but have also provided essential inputs for reduction of the data generated by many payload elements. Orbit determination for these missions has been carried out, without exception, using in-house expertise and software.

The new generation of ESA near-Earth missions, starting with the European Retrievable Carrier 'Eureca' and the first ESA Remote-Sensing Satellite ERS-1, and proceeding to the in-orbit infrastructure concept initiated by the Columbus project, present many new features, but also many that have been handled successfully in the past at ESOC. (The Eureca and Columbus projects are fully described elsewhere in this issue).

High-precision orbit determination for near-Earth orbiters brings us into contact with the rapidly developing area of space geodesy, in which new highly accurate measurement techniques and data-reduction procedures have revolutionised such fields as global and relative point positioning on the Earth's surface, ship navigation, and geodynamics (dynamics of the nonrigid Earth).

It was realised soon after the launch of the first artificial satellites that distance, Doppler or angular measurements made from ground stations to satellites contain information not only on the satellite's orbit, but also on many other physical parameters that enter into the description of its orbital motion or that of the tracking measurements. Some of these parameters are of major interest in themselves, such as:

- The Earth's gravity field, which determines the principal characteristics of the orbit. Large databases containing hundreds of thousands of preprocessed satellite-tracking measurements provide the starting point for development of global geopotential models. The satellite orbital parameters are a byproduct of the data-reduction process, and are eliminated as the normal equations are accumulated arc by arc.
- A well-determined orbit can provide a stable reference that can be used to determine the positions (and velocities) of points on the Earth as well as in space. By processing laser ranging or interferometric measurements, networks of globally distributed stations can be related to each other with accuracies of a few centimetres.
- The variable rotation of the Earth and the direction of its instantaneous spin axis can be measured by a number of techniques, several of which involve tracking Earth satellites. Again, the satellite orbit has to be solved for in order to extract the necessary parameters.

Thus high-precision orbit determination for near-Earth orbits is of indirect interest for a variety of scientific applications. It is often difficult, however, to separate the derivation of one set of physical parameters from another, since they can all affect the tracking measurements to a greater or lesser extent. Each researcher selects those data (orbits, measurement types) that are most sensitive to the parameters of relevance to his own area of study, but he will inevitably have to solve for (and eliminate) model parameters that are of lesser interest to him, or make use of models that may even have been derived in parallel from the same data. Some will place most emphasis on the orbit determination itself, others on the development of Earth-gravity and tidal models, still others on Earth-rotation and polar-motion determination, or on the determination of geodetic networks and their tectonic motions. However, all of these applications interact with one another and can never be treated in isolation.

The aims of precise-orbit-determination activities at ESOC might then be summarised as follows:

- Building on the considerable experience gained from many past missions, we seek to extend and apply the software tools for orbit determination and error analysis that have been developed in-house over a number of years. The outcome should be state-of-the-art software and models for the determination of near-Earth orbits, well-understood by the key users, and so maintainable and easily extendable as possible new applications are identified.
- The emphasis is placed on the creation of a routine operational capability for the support of future ESA missions requiring precise orbit determination. This implies a commitment to provide users of orbital data with a regular service and fast response time, implying highly automated and reliable software and procedures. This is a classical task for a spacecraft Operations Control Centre.
- Such an infrastructure activity is clearly of benefit for all our future operational orbit-determination efforts for near-Earth missions, and compliments project-specific preparations already underway for these missions. A software package is being developed which is generally applicable to all ESA near-Earth missions being considered for the next decade, and only relatively minor satellite-specific add-ons should be necessary in the future (e.g. models for spacecraft geometry).

The software element

The principal mode of operation of the ESOC orbit-determination software for near-Earth orbits involves the estimation of orbital and other model parameters from tracking measurements. A covariance/simulation mode permits pre-launch analysis of the orbit-determination process. Flexibility in the choice of parameters to be estimated is essential. Selection of an appropriate set of 'consider parameters' allows a sensitivity analysis to be made of the influence of uncertain model parameters on the state being estimated, and on the propagated position and velocity and Keplerian elements.

The software can be used as an orbit-integration tool. Moreover, a multi-satellite mode permits the simultaneous determination of several orbits from a combination of ground tracking and satellite-to-satellite tracking. Determinations and sensitivity analyses can be made in terms of both absolute and relative states (applications to rendezvous and docking, and multi-satellite configuration maintenance).

All of these functions are performed within a single program called 'BAHN', by the selection of relevant options. The parameters to be estimated or considered can include: the position and velocity of the satellite(s) at the epoch; coefficients for surface forces (drag, solar radiation, albedo, infrared); orbital manoeuvres; solid-Earth tides; station coordinates (and baselines); Earth-orientation parameters; measurement and timing biases; ionospheric/tropospheric model parameters; and the Earth's gravitational constant.

Table 1 indicates the range of the models currently implemented.

Figure 1 — Seasat 14-revolution arc and selected laser network

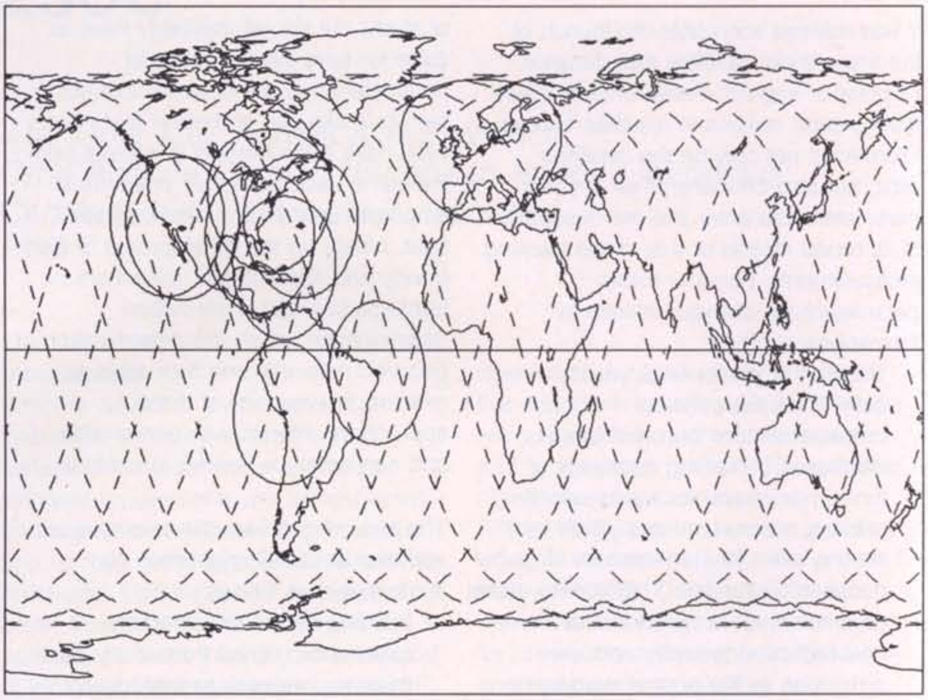


Table 1 — Summary of models in the 'BAHN' program

- Earth gravity field
- Luni-solar gravity
- Radiation pressure
- Solid-Earth tides
- Ocean tides
- Coordinate system
- Precession model
- Nutation model
- Sidereal time
- Station coordinates, polar motion, Earth rotation
- Troposphere

Applications

To illustrate some of the applications of the software to date, one example of covariance analysis and three examples of high-precision data processing (Seasat tracking, Seasat altimetry and Lageos laser ranging) will be briefly described.

Satellite-to-Satellite Tracking (SST)

Satellite-to-satellite ranging will be performed between Eureca and the geostationary spacecraft Olympus, and the data will be processed at ESOC. Among future SST missions involving high-precision tracking and applications to gravity-field modelling and oceanography could be a combination of Popsat (Precise Orbit-Positioning Satellite) and tracking of an ERS-class satellite (5900 and 800 km orbits, respectively, with inclinations of 98.6°). Popsat would be tracked by range and range-rate measurements from a network of 16 stations (assumed measurement noise 10 cm and 0.1 mm/s, biases 5 cm and 0.1 mm/s), while ERS could be tracked by two-station ranging (same accuracies). In addtion, an inter-satellite Doppler link is assumed.

An error analysis of a one-day orbit determination for both spacecraft has been performed based on an assumed error model for the various parameters that influence the orbit-determination process.

The Popsat orbit was assumed to be determined by ground tracking alone, ERS by ground tracking and SST. The results compare very well with an analysis made by the University of Delft using the ORAN program. As in other cases investigated, the most important error source by far is the gravity model. The SST range-rate bias is the second most important model error for the lower spacecraft, followed by air drag.

Analysis of Seasat tracking data

Given its similarities to ERS-1, analysis of Seasat data is considered a vital exercise in the preparations for the ERS mission. Data from a nine-station laser network (Fig. 1) and from an eleven-station S-band Doppler network (Fig. 2) have therefore been analysed. Seven three-day data arcs with relatively good coverage were selected and analysed individually.

At the time of Seasat launch, the laser stations had accuracies of 10—50 cm. The main drawbacks of this network are the non-optimal coverage, with most stations being located in middle- and low-latitude areas of North and South America, and the fact that only a fraction of the Seasat passes were tracked (lasers cannot observe through clouds). It can be seen from Figure 1 that only Kootwijk (Netherlands) provided data from Europe, and it contributed to only one of the selected arcs. The rms residuals of the laser ranges after adjustment of the Seasat orbit, the tracking station coordinates, an air-drag coefficient, and a solar-radiation-pressure coefficient were between 0.3 and 1.4 m, the latter value representing an interval of intense geomagnetic activity resulting in abnormally high drag errors.

The Seasat S-band data consisted of Doppler range-rates integrated over intervals of typically 30 s. Figure 2 shows that the S-band network had much more favourable coverage than the laser network. The high-latitude station in Alaska was in a position to receive seven to eight passes per day, and in fact it contributed most of the observations.

A number of determinations were performed in order to compare the results given by the laser and the S-band networks. The ESOC-derived station

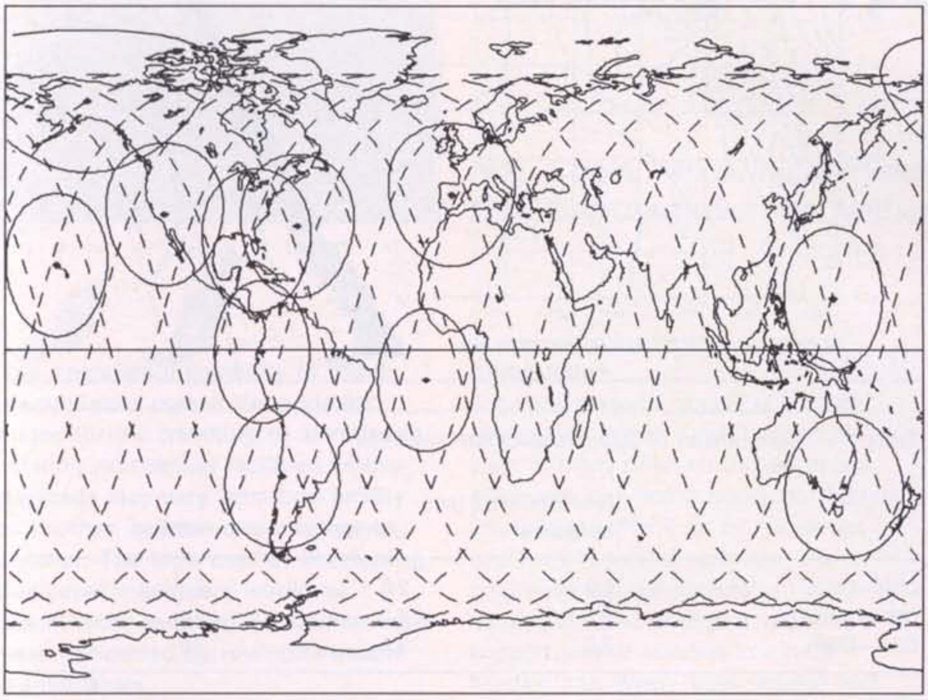


Figure 2 — Seasat 14-revolution arc and selected S-band network

coordinates were used for the laser solutions, while the NASA-derived (PGS-S4) coordinates were used for the S-band. For both types of data the estimated parameters in each three-day arc were the Seasat orbital elements, a drag coefficient, a radiation-pressure coefficient and the coordinates of the pole. In addition, an ionospheric scaling parameter per station was estimated in the S-band solutions.

Figure 3 shows the Seasat orbit differences between the laser and S-band solutions, resolved in the orbital reference frame. These differences are measures of the absolute orbit error, since the two networks are entirely independent. If one overlooks the results from arc number 7 (extremely high drag and insufficient laser coverage), it appears that the rms radial orbit error is of the order of 1 m.

Even better accuracies should be achievable for ERS-1 when it is tracked by a number of PRARE and laser stations. Simulations at ESOC and at Delft University suggest that 10 — 30 cm rms radial orbit accuracies are feasible, after elimination of the gravity-field errors by evaluating a tailored ERS-1 gravity model. Such accuracies are required in order to support the ERS-1 altimetry mission.

Figure 3 also shows that the Seasat along-track errors are of the order of 6—8 m, and the cross-track errors 1 — 3 m. The laser solutions were used to assess the Seasat orbit-prediction accuracy, by comparing the prediction from one 3 d arc with the orbit determination during the subsequent arc. The prediction accuracy is dependent on the levels of solar flux and geomagnetic activity, which influence the air drag on the satellite. It was found that a prediction interval of 2 d resulted in along-track errors of up to 700 m.

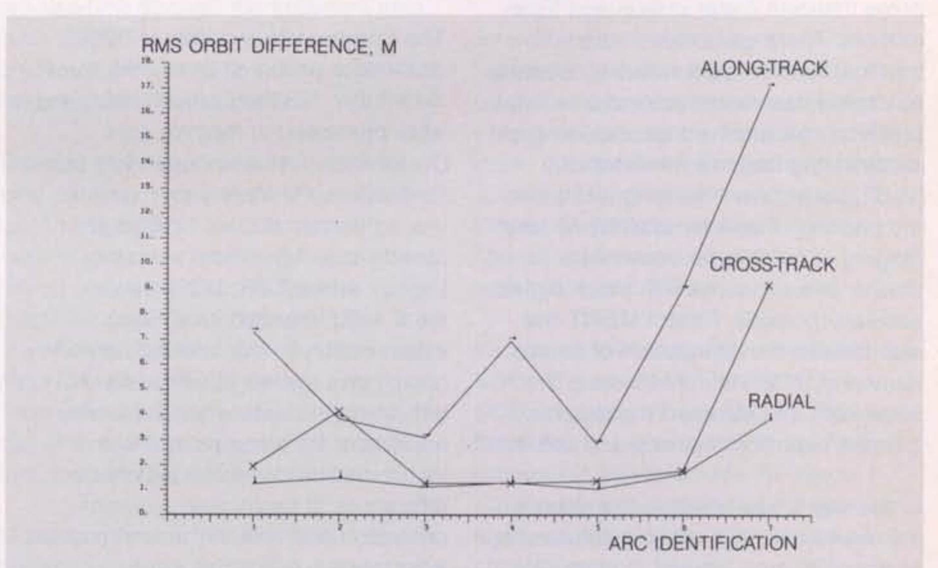


Figure 3 – RMS differences between laser and S-band orbit determinations

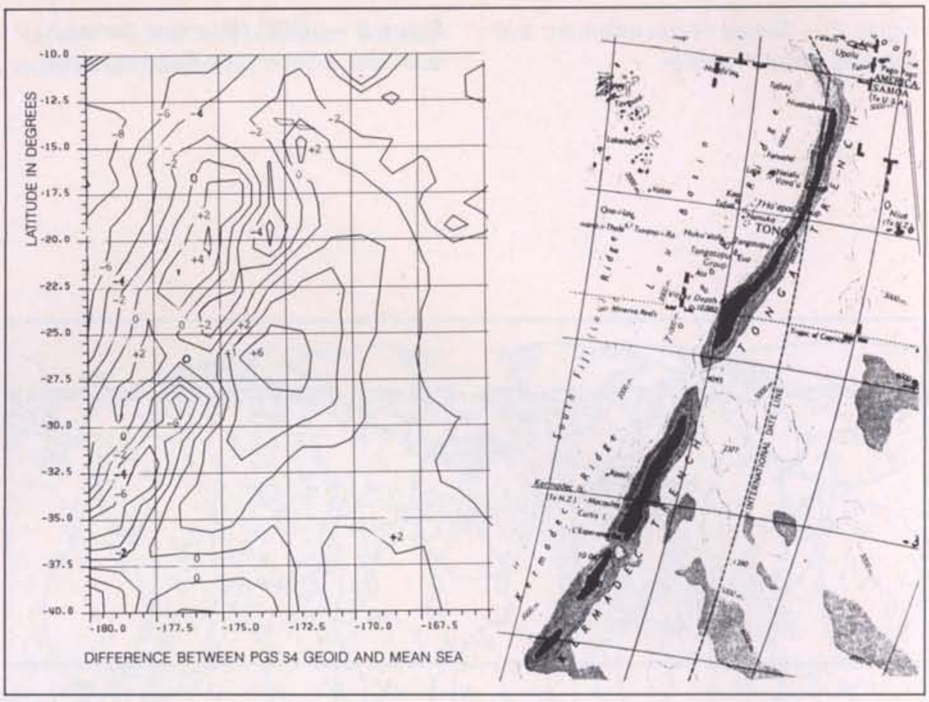
Seasat altimetry cross-overs

A satellite altimeter measurement is essentially the distance between the spacecraft and the instantaneous ocean surface, measured by the time of flight of a radar pulse from the satellite to the ocean surface and back (Fig. 4). A detailed analysis has been made at ESOC of a 23-day altimetry dataset from the Seasat mission, as a first step towards implementation of altimetry measurements in the orbit-determination process, and as a method of assessing the radial orbit errors remaining on the ephemeris (PGS-S4) computed at NASA/GSFC.

The technique used to process the altimeter data is known as 'cross-over analysis', and it results in detailed maps of the mean sea-surface topography over areas of typically 30°×30° in longitude and latitude. The cross-over technique is based on two assumptions: firstly, that

Figure 4 — Principle of altimetry measurement

Figure 5 — Sea-surface topography from Seasat altimetry over the Kermadec and Tonga Trenches



the height of the ocean surface is constant at the intersection of an ascending and a descending satellite pass, after all known time-varying effects have been removed (tides, barotropic effects, currents); and secondly that, over a limited area (e.g. 30°×30°), the radial satellite orbit error can be modelled by a slope and bias on each arc.

Figure 5 shows the sea-surface topography deduced in this way for an area between New Zealand and American Samoa. To bring out the fine detail, the topography is plotted with respect to the NASA PGS-S4 geoid model. The region includes two 10 km-deep trenches, Kermadec and Tonga, which are clearly visible in the plot. The a priori rms cross-over residual for this area was 3.5 m; after adjustment this reduced to 17 cm, this latter figure being indicative of the level of the radial orbit error remaining.

Project MERIT

An important step forward in our precise-orbit-determination activities resulted from participation in the 'MERIT' project. This was an international measurement and data-reduction campaign aimed at comparing the various techniques available for monitoring the orientation in space of the Earth's rotation axis and prime meridian (polar motion and Earth rotation). These parameters have traditionally been determined by classical astrometry, but recent advances in high-precision measurement techniques such as Very-Long-Baseline Interferometry (VLBI), Lunar Laser Ranging (LLR) and the tracking of artificial satellites by laser ranging or by Doppler have made routine determinations with much higher accuracy possible. Project MERIT has also allowed the comparison of results derived by different centres using the same data and standard models, but different reduction methods and software.

In this way it was possible to compare the results obtained with our software, by analysing a large amount of laser-ranging data from the Laser Geodynamics Satellite (Lageos), with results obtained by the NASA/GSFC orbit-determination program GEODYN, the University of Texas (CSR) program UTOPIA, the MGM software of the Deutsches Geodëtisches Forschungsinstitut (DGFI) and others. It was also possible to make absolute comparisons with the results obtained by the completely independent, very precise VLBI technique.

Table 2 — Comparison of station-coordinate solutions

	Rms difference (cm) Longitude	Latitude	Altitude
CSR—ESOC	2.0	2.6	2.1
DGFI—ESOC	0.7	2.2	4.4
CSR—DGFI	2.0	2.4	3.6

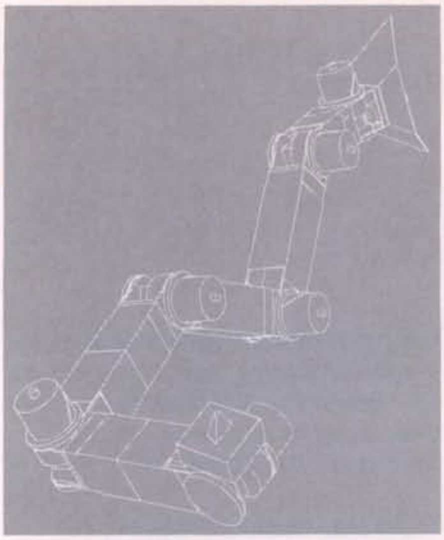
The Lageos data available at ESOC spanned a period of 14 months, from September 1983 to October 1984, and were processed in monthly arcs. Comparison with an independent solution for the pole, the VLBI series, gave an rms agreement of 3 — 4 milliarcsec (9 — 12 cm). Agreement with other Lageos series (CSR, DGFI) was at the 2 — 3 milliarcsec level. The initial solution for the tracking network coordinates agreed to within about 6 cm with the other Lageos solutions, after adjustment for a seven-parameter transformation to remove systematic differences of origin, reference-axis orientation and scale. A recent multi-arc adjustment in which the station coordinates and Earth rotation parameters were recomputed over a 14-month period showed an rms agreement of about 2 cm with the University of Texas (CSR) solution (Table 2), which was derived from a much larger data set.

Conclusions

The objectives of the precise-orbit-determination activity at ESOC for near-Earth orbiters have been outlined, and a brief overview of the software being developed given. The four examples chosen to illustrate current capabilities — satellite-to-satellite tracking, Seasat tracking, Seasat altimeter cross-overs, and Lageos laser ranging for geodynamic studies — indicate that significant progress has been made towards achieving those objectives.

Acknowledgment

G. Lecohier and M.J.H. Walker made important contributions to the work reported in this article, which is based on two prior presentations, at the Second International Symposium on Spacecraft Flight Dynamics in Darmstadt in October 1986 (ESA SP-255).



Robot Manipulators for Sample Handling in Space

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The operational flexibility of robot manipulators makes them ideally suited for the handling of samples in orbiting processing facilities whose payloads may vary from one facility to another, or from one mission to another. The high cost of developing dedicated machinery would be significantly reduced if common tasks were performed by reprogrammable manipulators.

Introduction

The most powerful appeal of a robot manipulator is that it can perform the tasks of many different single-purpose machines, its function being modified by instructions rather than by the design and manufacture of hardware. The equipment can be re-used on subsequent and divergent missions, or to support several activities in a multi-function role. When mass, volume and complexity are critical, as in space, this property is of enormous value.

Robot manipulators have particular potential for the in-orbit processing of metallic and biological substances, to exploit the improvements in structure and purity obtainable by processing in microgravity conditions. The nature of these materials means that they have to be treated in the form of discrete bodies rather than in flow processes, passing one-at-a-time through the treatment area, such as the furnace in a materials processor. The items thus have to be moved around in the facility.

The cost of keeping people in orbit for long periods, to operate and service the facilities, is so high that unmanned orbiting platforms are being designed for this type of work, using automatic machines to perform the tasks. Even in manned laboratories, such as those that are included in the Columbus Programme, the demands upon the crews' time will be so great that much of the work will have to be automated.

Moving an item is the very reason for the existence of a mechanism, but up to now, all spacecraft mechanisms have had to maintain a hold on the item being moved, or to release it for ever. For space processing, however, the item must be moved from one place to another (Fig. 1), which means a series of exchanges between mechanisms. Control of the item must never be lost and its transfer from one mechanism to the next is particularly critical. In orbiting processing facilities this has to be done remotely and automatically, without direct human intervention.

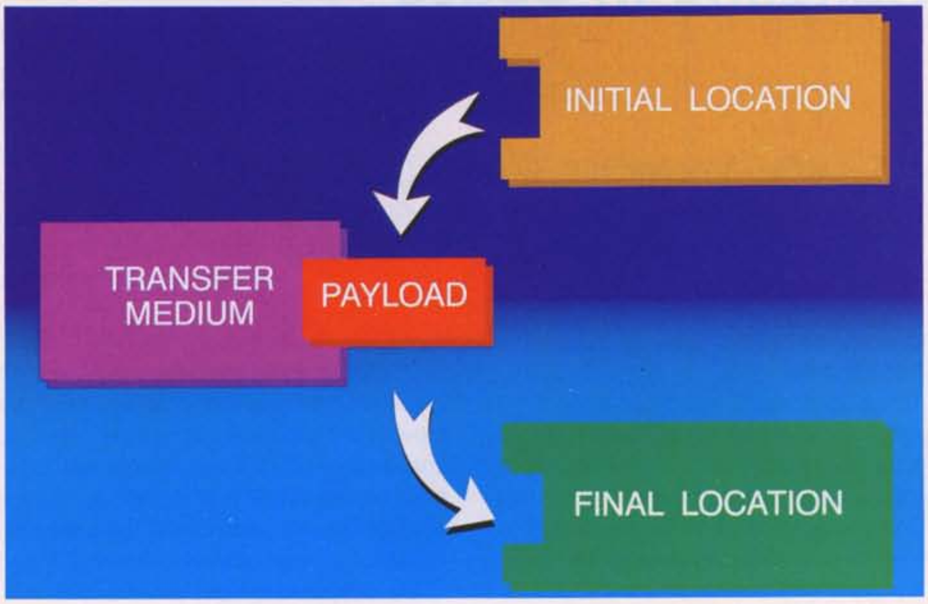
At first sight, it may be thought that only crude mechanisms are needed for this task, but the transfer of items between mechanisms demands a higher level of precision and complexity higher than is at first apparent. Furthermore, in many cases the machines are purpose-built for a single task and, apart from sporadic use, lie idle for much of their lives.

To explore the technical problems associated with this subject, the Agency placed a study contract, completed in early 1986, to examine the salient points in the application of robotics on the small scale. An industrial team comprising Dornier System, Sener and Fokker carried out the work under the supervision of ESTEC.

As an example application, the Automatic Mirror Furnace (AMF) facility for the Eureca spacecraft was chosen. Although the exacting requirements of the AMF processing itself preclude the use of a robot-manipulator, the other transport tasks in the facility are well within its capabilities.

Figure 1 — Essential relationships in the moving of samples by manipulator

Figure 2 — Computer-generated image of the skeleton manipulator



The basic concept
To establish a cost comparison between manipulator- and dedicated-mechanism-configured facilities it was necessary to consider a manipulator providing only the same functions as in the chosen example. This fails, however, to exploit fully the versatility of a more sophisticated manipulator, so the study arrived at two manipulator concepts, the so-called 'Skeleton' and the 'Advanced'.

Although the initial aim was that the skeleton should be a simplified version of the advanced concept, fulfilment of the particular requirements for each led to individual designs, as will become clear. The skeleton will be described in detail first, followed by a description of the particular features of the advanced manipulator concept.

The manipulator is like an arm in many ways, but it is important that this idea is not taken further, as it leads to wrong assumptions concerning both the capabilities and the limitations of the robot arm.

For the test case, a minimum of four degrees-of-freedom is needed for the manipulator, so this is the number provided in the skeleton concept (Fig. 2).

The end-effector
The end-effector is the device at the end of the arm used for grasping the object to be moved. Without it, the manipulator would be of little use. It is often assumed that the end-effector must be a hand-like device, but this is certainly not the case, and even pincer-jaws are not needed in most applications.

The human hand has evolved to its present form because of the great variety of shapes, weights, and textures with which it has to cope at random. Its design is not, therefore, optimised for any particular activity. However, in these robot applications, the designer has a high level of control over the interface on the object to be manipulated, to the extent that identical interfaces can be provided on every item to be grasped.

The fundamental rule in manipulation is that control of the item to be moved must be maintained at all times. This means that it may only be released from the first support when adequately restrained by the next, and so on. This has additional

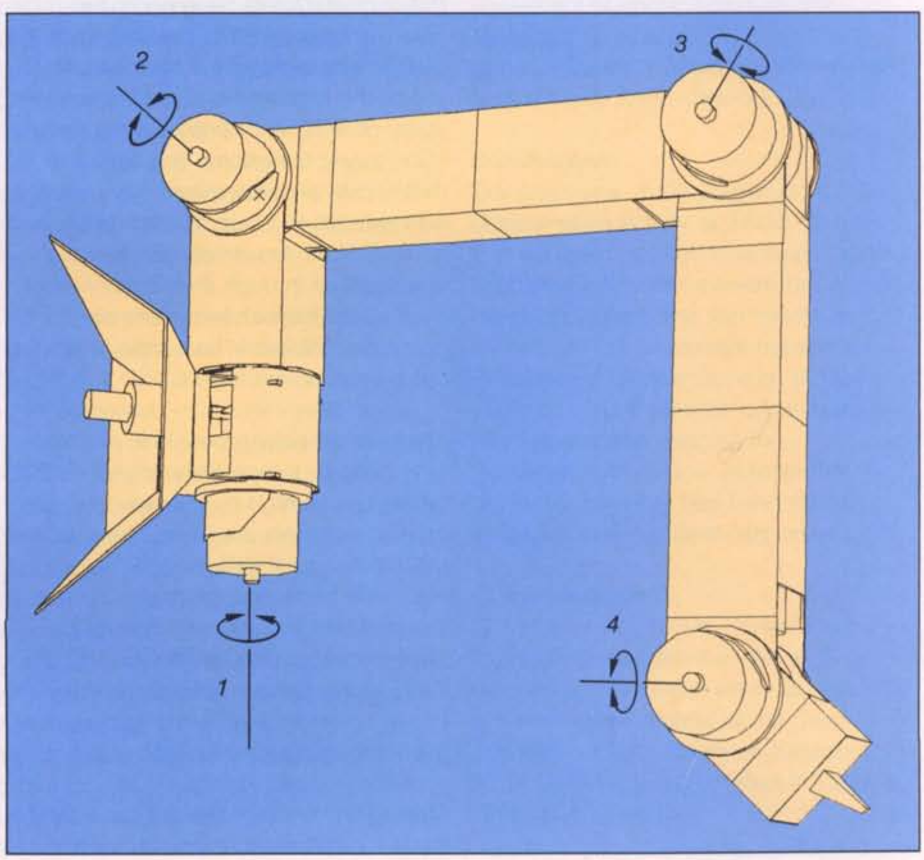
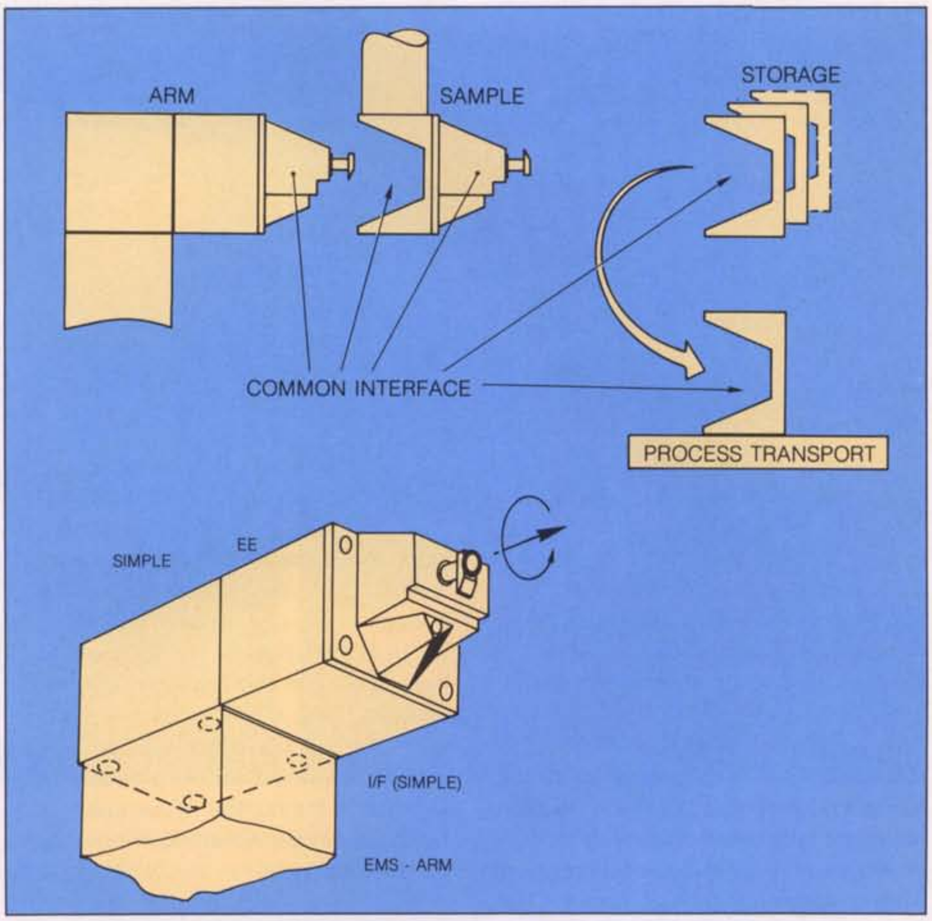


Figure 3 — Simple interface for both end-effector and stowage attachment



advantages in simplifying the design requirements for both end-effector and the arm itself since no unexpected orientations of the object can be allowed to occur.

The design of the end-effector and the grapple-fixture that complements it can therefore be simplified to include only specifically chosen properties.

The Tetrahedral Wedge Joint*, which has recently been patented by the Agency, provides the necessary properties for both the end-effector and grapple-fixture functions in one simple device.

It will frequently be necessary to provide mechanical and electrical power and signal transfer across the interface, and this is assisted by a simplified design. The electrical connector can be accommodated close to the structural interface, allowing a compact configuration of the ensemble (Fig. 3).

Storage and process interfaces
The end-effector to grapple-fixture interface is not the only critical interface. For launch and landing, the samples require firm fixing to keep them intact and correctly positioned against the possible 25 g disturbances, and for processing accurate location is essential. Any means of restraint must also release completely to allow movement to the next location, so the functional requirements are similar to those for the end-effector.

In the furnace facility, the attachment of the payload to its storage position has to be very close to the end-effector interface, so a compact, simple end-effector also enables the use of similar devices which can be placed in series, to the benefit of grapple-fixture compactness.

*European Patent No. 0194169, granted to the European Space Agency. Inventor: N.E. Cable

Using a similar grapple-fixture interface on the process transport mechanism would enable the same device to be used for the attachment of the sample, thus minimising the hardware.

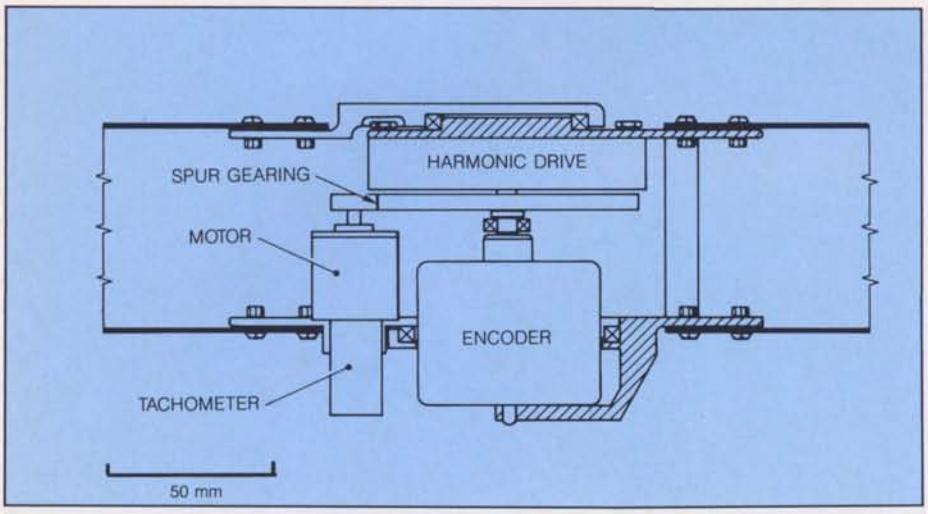
Figure 3 shows how a simple interface based on the Tetrahedral Wedge can provide all the necessary features for a manipulator end-effector, grapple-fixture, storage-support and process-drive attachment in a compact design.

Existing products
When investigating existing manipulators for their suitability or adaptability, it was clear that, as most were for Earth-bound work only, they had major disadvantages for space use. Commercial manipulators operating under gravity, not governed by strict volume and mass requirements and easily accessible for supervision and frequent servicing, would require extensive modification to be usable in the space domain. A manipulator purpose-built for space operation was thus needed.

To keep development costs low, a modular approach was adopted so that the same components could be used for each segment of the arm. Linear and rotary actuators were investigated and an all-revolute (Fig. 4) configuration was found to be the best in the light of all the requirements.

Design considerations
The major influence on the design is the need for the manipulator to fit in the limited space available in a Eureca payload module, allowing sufficient samples to be carried, whilst having adequate reach and flexibility, accuracy, strength and reliability. The volume of the

Figure 4 — Modular joint layout



arm segments and hinges occupies a significant part of the working volume and restricts the very operation of the arm itself, so every possibility was pursued to minimise the size of the arm.

An arm with all motors controlled by an electronics unit at the base needs a harness so thick and stiff that it becomes unusable. Distributed electronics communicating by means of a redundant serial interface bus (MACS) have the double advantage of minimising the wiring and contributing to the modularity of the arm segments.

Hollow, 64 mm square-section arms of aluminium or carbon-fibre provide the necessary rigidity and enable the electronic packages to be fitted within. To achieve the necessary reach for the facility application, the arm is 820 mm long, comprising inter-joint sections of 320 mm, with base and end-effector stubs of 80 and 100 mm, respectively.

The main electronics unit does not have to be accommodated within the facility volume, but the design aim is to keep its size and mass to a minimum.

The volume-efficiency of the storage on dedicated mechanisms is low, so the overall capacity of the facility is limited. However, this is not a design-driver in this case, as sample processing takes a long time and limits the number that can be treated on any one mission. But, with a layout of the whole facility optimised for storage volume and functional volume, the positioning of the furnace in one corner of the cuboid and the use of a manipulator would lead to a threefold increase in the number of samples processed in the Automatic Mirror Furnace facility.

The shape of the storage volume is directly influenced by the number of degrees-of-freedom in the arm. In the case of the skeleton, a cylindrical shape is determined by the reach of the manipulator. Figures 5 and 6 show the skeleton manipulator in the reconfigured facility with this storage layout.

The skeleton has to exert, through the arm itself, the force needed to insert and withdraw an electrical connector, so the sizing of components has to be made accordingly large.

Due to the firmness of the fixing needed for the samples during launch and landing, positioning accuracy for the end-effector must be high and the compliance for its alignment with the sample must be provided by the arm. Since only passive compliance is provided in the test facility, the skeleton is limited to this too. As the control provisions are limited, system considerations lead to the choice of back-driveable joints.

The overall configuration provides end-effector positioning within 0.5 mm and 0.2 deg, sample exchange within 10 min without violating the microgravity disturbance requirement, and a 20 N output force at the end-effector.

Sensors

Sensors are needed for the basic operation of the manipulator. Position control requires measurements at the angles between arm segments, and control of the accelerations produced within the microgravity disturbance limits needs angular velocity measurements. The accuracy requirements for the mechanisms are not diminished by the use of sensors.

Force and torque sensing would be beneficial to manipulator operation, but would lead to increased size, complexity and cost, which were not justified for the skeleton concept. Reliance is placed on the passive compliance offered by the arm in the final adjustment of end-effector positioning.

Redundancy

Because of the inaccessibility of the facility in orbit, redundancy provisions would have to be made. A major influence on this is the credibility of the failures to be prevented: care in the choice of measures is needed to ensure that they are both essential and correct as the features themselves may be a cause of degradation in performance or reliability.

The skeleton concept provides only one drive-set per articulation, thus providing the same level of redundancy as in the AMF. However, the sizes of the components have been chosen to cope with the anticipated loads with a good margin, resulting in high confidence for reliable performance.

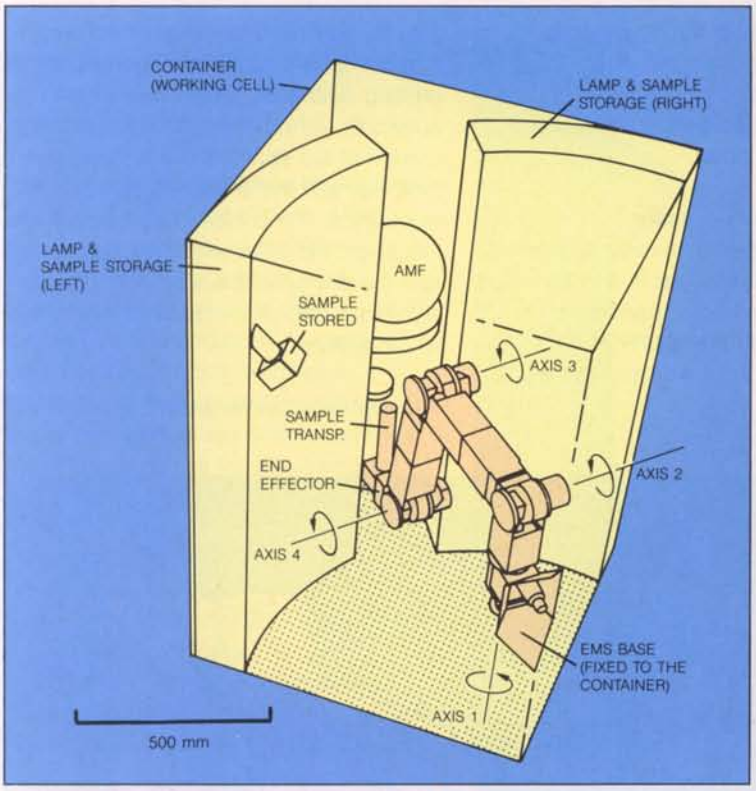


Figure 5 — Computer-graphics-generated view of the skeleton manipulator within the experiment facility

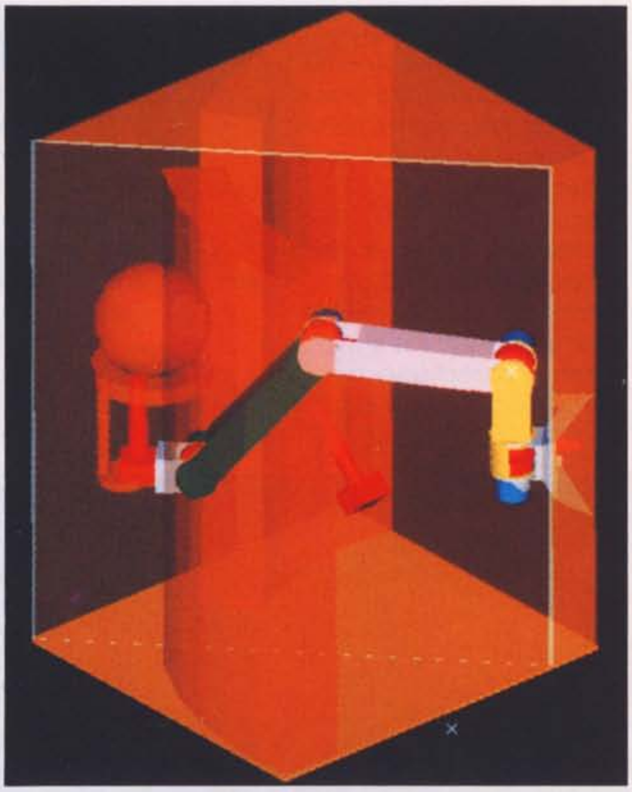


Figure 6 — Computer-graphics-generated image of the skeleton manipulator in the furnace-facility application (generated by Dornier using Geomod)

For the emergency case where the sample is still in the grasp of the manipulator arm on landing, an externally-applied block is adopted for the skeleton in order to reduce size and complexity, as the risk is considered to be very low.

Ground testing

The success of the facility depends very much on the accurate definition and execution of the required operations. This means extensive ground exercising to define these operations and to check the equipment to be flown.

Optimising an arm for microgravity operation gives the most compact design but, when operated on Earth, the forces and moments exerted on the manipulator by gravity will tend to prevent the positioning requirements being met.

Compensatory measures are needed in the development work. As an example, the use of air-bearings would allow operations to be tested in a horizontal plane using flight-sized equipment, although this would not allow full three-dimensional demonstration.

For a full facility demonstration on the ground, a purpose-built arm will be required to overcome the effects of gravity. As the arm will form a cantilever, the moment loads will increase towards the base of the arm, resulting in a need for progressively larger components. If identical components are imposed in this case, the parts further away from the base will be larger than otherwise necessary, and so increase the gravity-induced deflections and volume occupied still further. Despite the additional cost, a graduated sizing will be needed.

Computer-aided design

Although two different models will be required, one for ground and one for orbit use, the number of different examples can be limited by the use of the new synthesis and analysis tools now available. Computer-aided design and solid-modelling techniques have shown themselves to be essential tools in this work.

Initially, allowing realistic layouts and complex three-dimensional fit and movement checks, both design and operations definition can be carried out to a high level of completion before any hardware construction, resulting in large cost and time savings.

The completed model, refined to the standard of the hardware eventually to be built, can then be used to refine the operational procedures of the manipulator and even to try out new cases and configurations.

Figures 2, 5, 6, 7 and 8 were all generated using these computer tools, and the models can easily be used for further exercises in increasing knowledge and understanding of the application. The immediacy of the results itself assists rapid identification of the real problems and their solution.

Figure 7 — Computer-generated image of the advanced manipulator (six degrees-of-freedom)

Processor
Due to the limitations on direct communication with the ground a high degree of autonomy will be required in the manipulator, provided by an on-board processor.

For the same reason, each facility requires a processor to control its own operations. As this will need to communicate with the manipulator processor, distinct advantages can be seen if the manipulator processor were to be given the role of facility controller. The complete facility operation would then be run by only one computer, which would simplify the system design and reduce complexity and mass.

Electronics and software
Although this article is mainly concerned with mechanical aspects, it is to be noted that the success of the manipulator is directly related to the quality of the electronics and software used to control its operations.

Due to the limited communication time with the ground and high workload of orbiting operators, a high degree of autonomy will be needed. Much of the burden of the success of the facility will thus rest with the software and the electronics. The choice of computer language, the development of software and the design of the electronics form a significant part of the development of the whole system.

The electronics units are subject to the

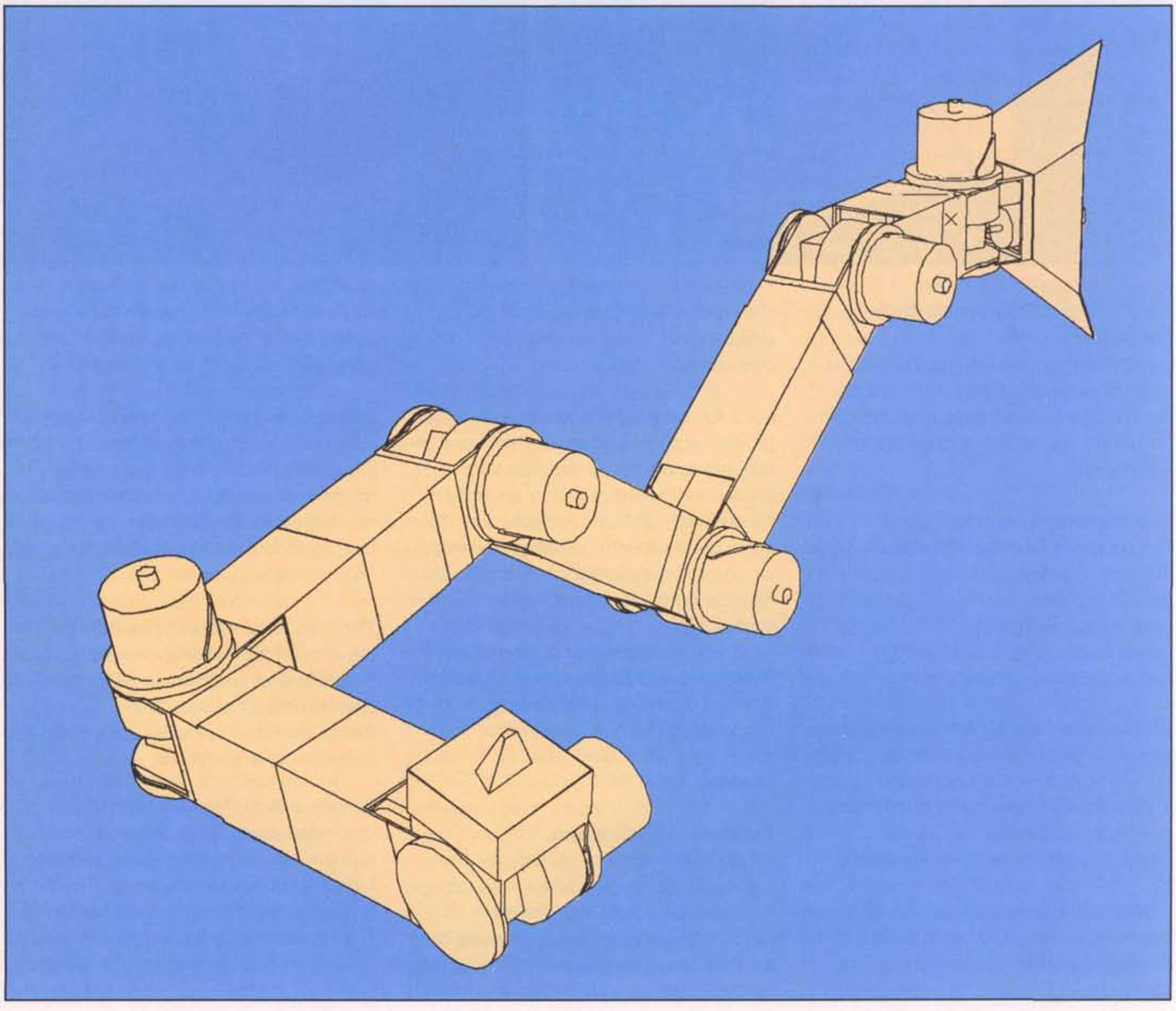
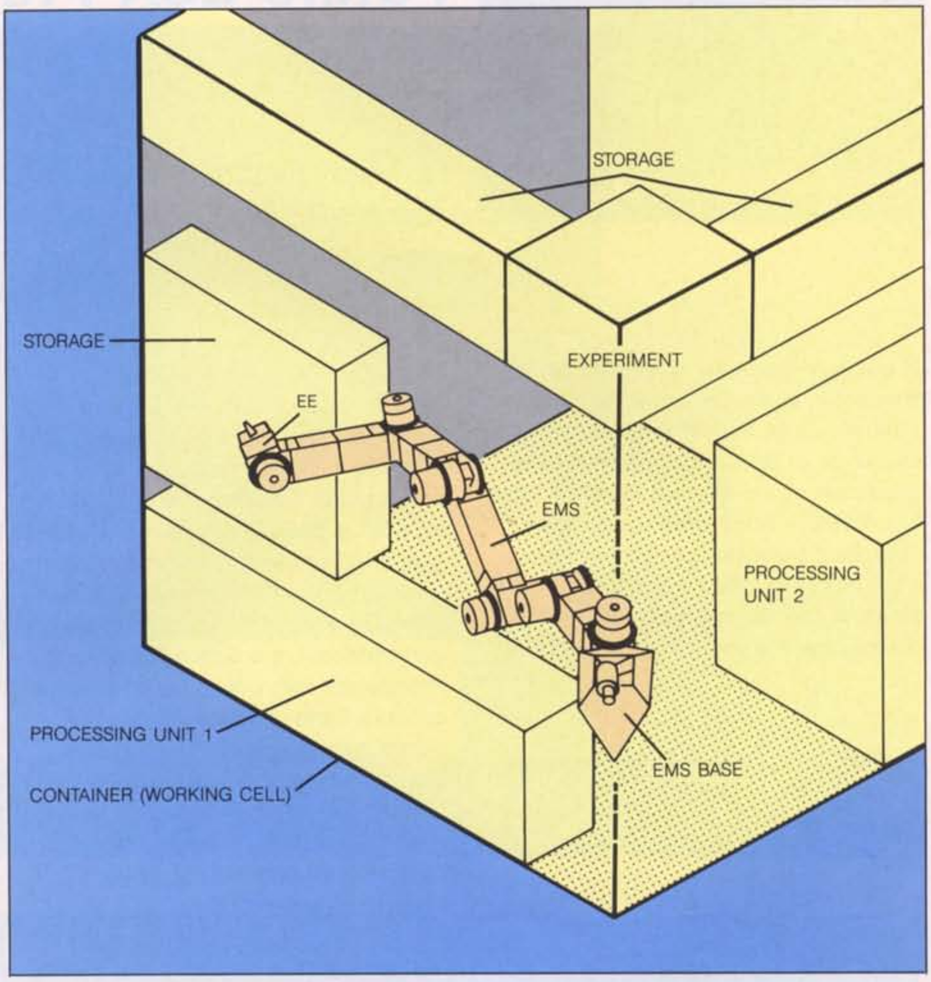


Figure 8 — Computer-graphics-generated view of an advanced manipulator servicing a number of facilities



same physical requirements on performance, robustness, mass and volume limitation as the arm itself, necessitating similar attention to detail.

The 'Advanced' manipulator concept
The advanced concept is one which exploits the versatility of manipulators to support a wide range of applications using essentially only one design. While a similar design philosophy regarding distributed electronics, all-revolute configuration and structure is followed, the components of the skeleton are not the optimum choice for the advanced application, and so a new definition is necessary.

The complex orientations required of the end-effector mean that additional degrees of freedom are needed. This is accomplished by the use of more joint modules to provide the requisite number of articulations. Figure 7 shows a typical six-degree-of-freedom manipulator suitable for this application.

Force-torque sensing at the wrist gives active position control and allows the use of stiff, non-backdriveable hinges which make use of spiroid gearing. A vision system would enable active adjustment of the paths and greater flexibility of operation, though at an appreciable cost.

While a simple end-effector interface is retained, a motor-driven lock is provided for restraint during launch and landing. Powered connector operation, minimising strength requirements for the arm by local off-loading, can be implemented and a variety of specialised tools can be used, each being attachable to the arm via this interface. A torque-drive can be provided adjacent to the connectors, for mechanical power transfer.

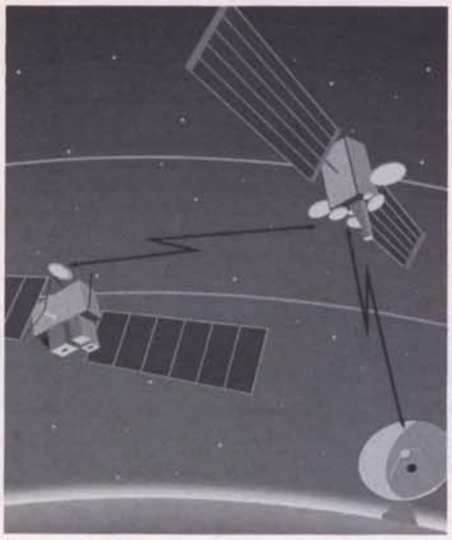
An advanced manipulator could serve a number of different facilities, suitably arrayed, by appropriate phasing of the operations and the provision of the appropriate tools (Fig. 8).

The reliability demands would be higher in this event, so the proposed configuration includes redundant drive-sets at each articulation and redundant electronics and wiring. Individual blocking means could be implemented on each joint.

While the resultant manipulator is larger and heavier than the skeleton, it is anticipated that additional space would be available from the overall volume saving.

Conclusion
The study has shown that application of robotics on the small scale is a viable approach. While some of their components will need development to make them suitable for space use, manipulators can offer significant advantages in the handling of samples in orbit. Their operational flexibility enables re-use of hardware, both between facilities and between missions, thus saving on the development costs of dedicated machinery. Additional savings in mass, volume and all-supporting functions, such as power and thermal control, would stem from use in a multi-functional role, serving a number of process and experimental facilities.

Further studies are planned to investigate the application of manipulators to groups of facilities, such as those envisaged for the Columbus Programme, in both manned and unmanned orbiting spacecraft.



The Role of Microwaves in Future ESA Programmes

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Microwave systems, equipment and components are expected to play a crucial role in supporting many elements of ESA's long-term space programme. An attempt is made here to provide a brief insight into their contribution in the context of the eight major themes that form the basis of the overall research and development effort.

At the ESA Council Meeting at Ministerial Level in Rome in January 1985, a Long-Term Plan was approved for space activities in Europe until the year 2000 and beyond. This plan focusses on and supports a basic space infrastructure with a view to European autonomy. It foresees transportation with the Ariane-4 and -5 launchers and the Hermes spaceplane; participation in the Space-Station Programme with Columbus; preparation of future Earth-observation and communications-satellite systems; and increased funding for space science, allowing Europe to undertake planetary exploration and build large astrophysical observatories operating at as yet unexplored wavelengths.

Microwaves are only a small part of the electromagnetic spectrum used for space missions but the full range of microwaves, ranging from VHF communications for simple telemetry and telecommanding to submillimetre-wave techniques for radiometric and spectroscopic observations, will be exploited. The centimetre waves are transmitted without excessive attenuation through the atmosphere and allow reliable communications. The shorter wavelengths, starting with millimetre waves, do not reach the Earth's surface, but satellites orbiting above the propagation barriers can receive them very effectively.

Microwaves will be used for applications missions like telecommunications, remote-sensing, and microgravity utilisation; for scientific research into the Earth's environment; for deep-space and astronomical research; and last but not least to support such functions as spacecraft communications, commanding, and navigation.

The development of a basic European space infrastructure and of scientific and application payloads is well provided for in the ESA Long-Term Plan with an extensive and clearly defined Technological Research Programme.

The studies and technology development efforts needed to support the Agency's current and future programmes are organised around eight major themes. I will attempt here to highlight the role that microwaves can be expected to play in each of these eight areas (Fig. 1), and to identify the critical technologies.

The Earth—Space Telematics Network

The ESA Earth—Space Telematics Network is the complete end-to-end data system required to establish an interactive two-way link between the instrument, or sensor, flown in space and the end user of the information that is collected. This complex system, which must perform a variety of functions — conditioning, transmission, processing, storage, and archiving of the data — will undergo a dramatic evolution in the coming years. This evolution will be due partly to the increase in volume and complexity of the data streams that will be generated by future spacecraft — up to hundreds of megabits per second for those designed for Earth-observation and other imaging missions — and partly to the evolution in the relevant communications and data-handling techniques, such as the

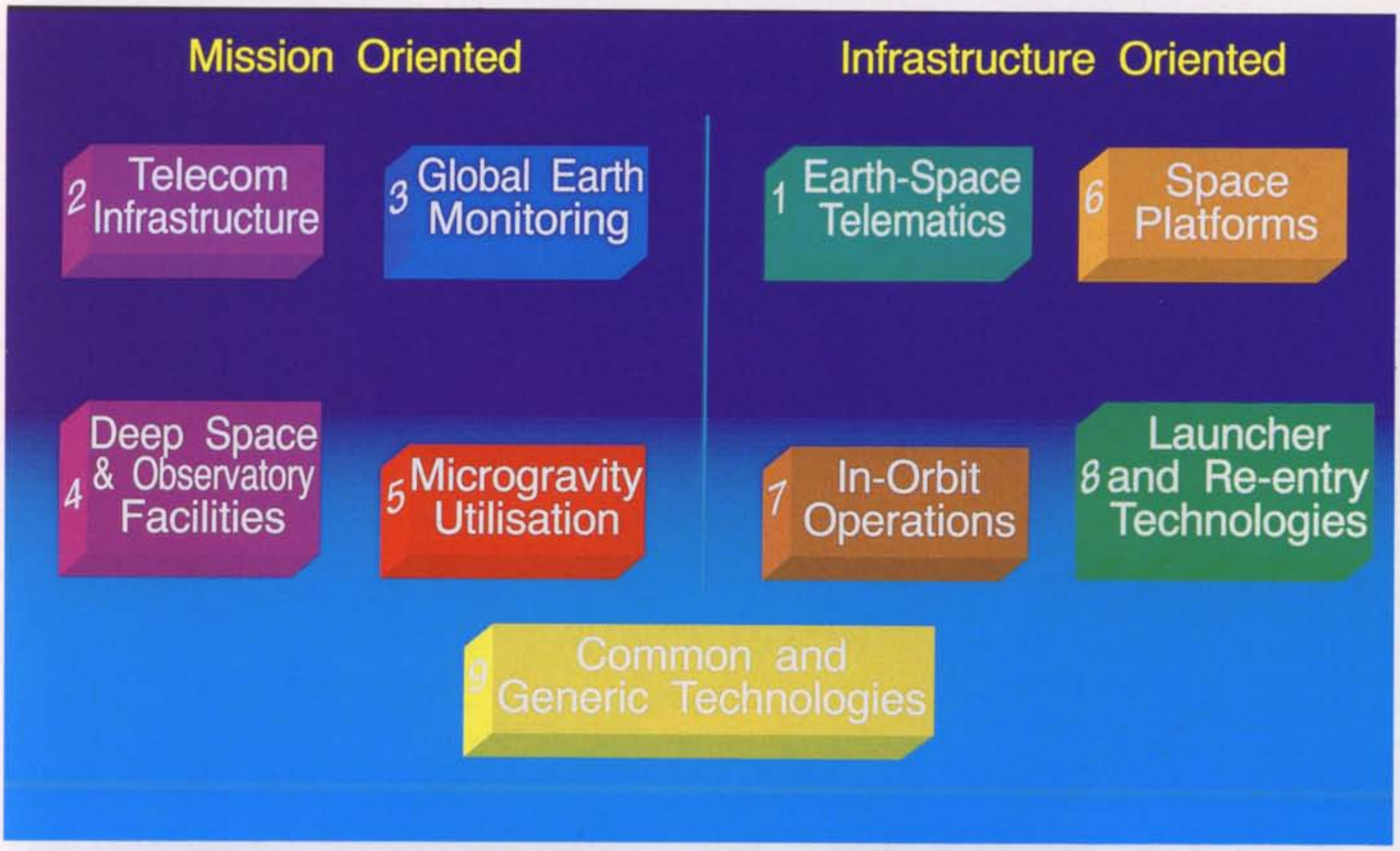


Figure 1 — The themes of ESA's technological R & D programmes

introduction of a Data Relay Satellite (DRS) system (Fig. 2).

The European DRS system, with two satellites in geostationary orbit, will replace the large ground network that is otherwise necessary to provide full Earth coverage.

The European DRS will work at S-band for compatibility with the US Tracking and Data Relay Satellite System (TDRSS). Low-data-rate satellite terminals (up to 5 Mbit/s) will be employed with a phased-array antenna to point the beams at the geostationary satellite, which will be equipped with 5 m (or larger) antennas with deployable reflectors.

High-data-rate streams reaching 500 Mbit/s in frequency multiplex will be transmitted in the Ka band (27 GHz) from satellites in low-Earth orbit with high-power TWT amplifiers and autotracking 1 m antennas.

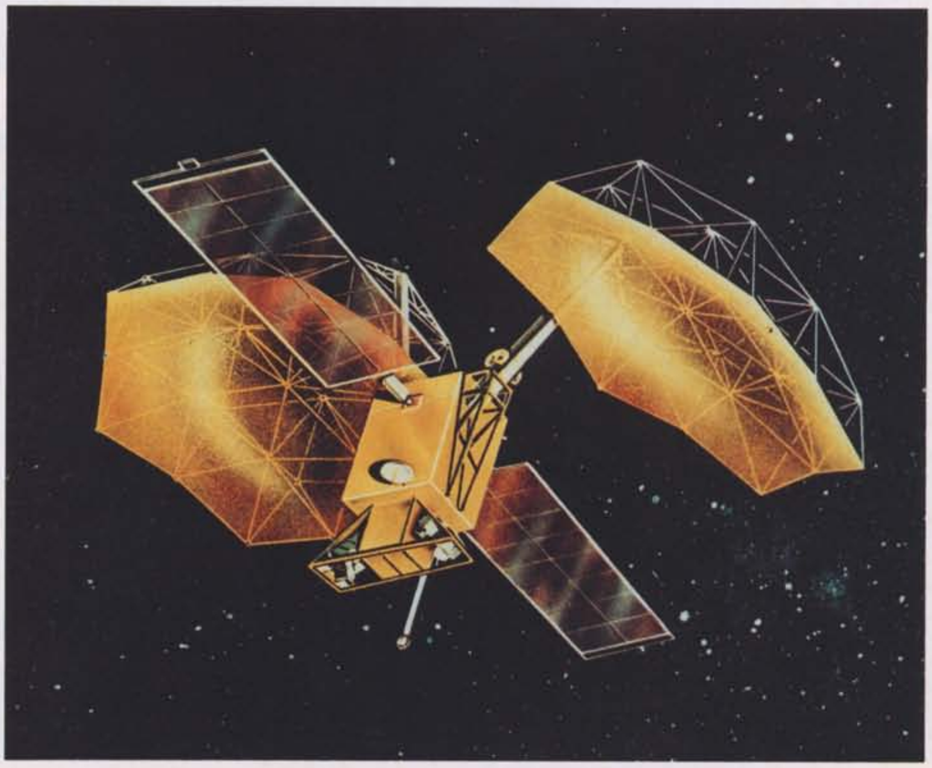


Figure 2 — Artist's impression of a Data-Relay Satellite

Figure 3 — Feed array and beam-forming network for a Eutelsat contoured-beam antenna

The 20 and 30 GHz bands will be used for direct transmissions from the European DRS system to the many ground stations of the European data users.

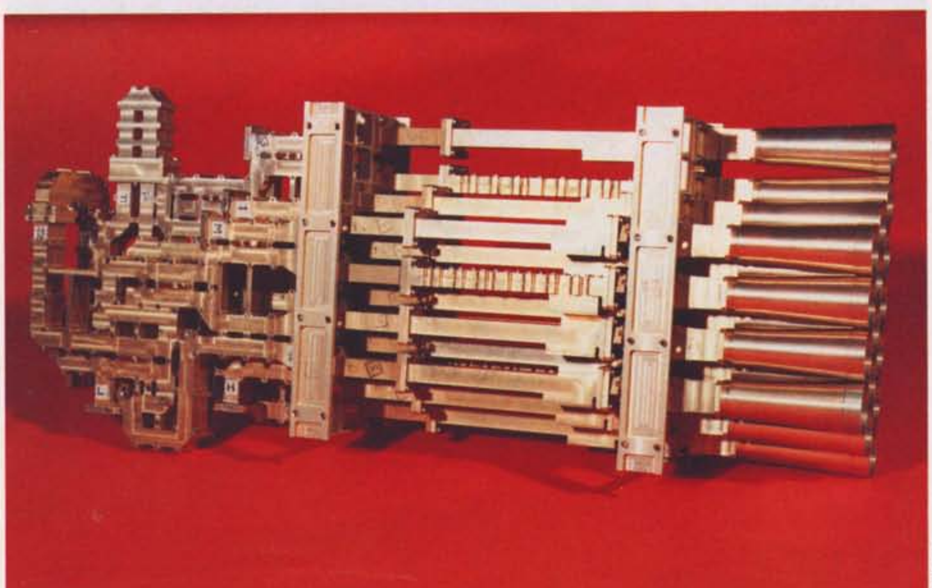
Infrastructure for space communications

The objective here is to prepare the technology infrastructure required for future telecommunications-satellite payloads and services. Development is justified on the one hand by the increased traffic and new services being introduced (data transmission to small terminals, electronic mail, video-conferencing, etc.), and on the other by the technological evolution that is taking place in terms of more powerful and operationally flexible satellite systems with larger antennas, for contoured- and multiple-beam operation and extensive frequency re-use.

Eutelsat-II uses transparent 14–11 GHz transponders and contoured-beam antennas (Fig. 3). Italsat will have six spot beams with 30–20 GHz regenerative repeaters and digital baseband switching.

Having guided the development of these technologies, ESA is now preparing the next generation of fixed-service communication satellites, which will provide European coverage with overlapping high-gain spot beams generated from 4 m reflector and feed-array antennas. Extensive use of signal processing — demodulation, switching, coding and remodulation — provides full interconnectivity and coverage flexibility. Direct access to users' small terminals and a very large communications capacity with onboard switching functions (Fig. 4) in each satellite will make space communications very competitive with future optical-fibre networks.

The largest part of ESA's microwave development work is focussed on this second theme, ranging from studies for 60 GHz links between satellites to development work for land-mobile communications at L-band (Fig. 5). The use of active arrays, probably positioned in the focal planes of larger reflector antennas (up to 12 m in diameter and larger), will permit multiple steerable coverage beams to be exploited (Fig. 6). Advanced technologies will therefore need to be qualified for space use, ranging from the active array elements with monolithic solid-state amplifiers mentioned above, to optical fibres for signal distribution to them and to inflatable space-rigidised reflectors.



Selenia

For higher frequencies and transmitter powers, particularly on broadcasting satellites, microwave amplifier tubes will need to be further developed, striving for higher efficiency, improved linearity, and longer lifetimes. In-orbit re-configurability (by means of switches, variable power dividers, tunable filters and multiplexers in multi-element feeds) is also called for to allow payloads to be adapted in orbit to varying service and coverage requirements.

Global Earth monitoring

This theme embraces the development of the advanced remote-sensing instrumentation necessary for Earth observation for both monitoring (applications) and scientific-research purposes.

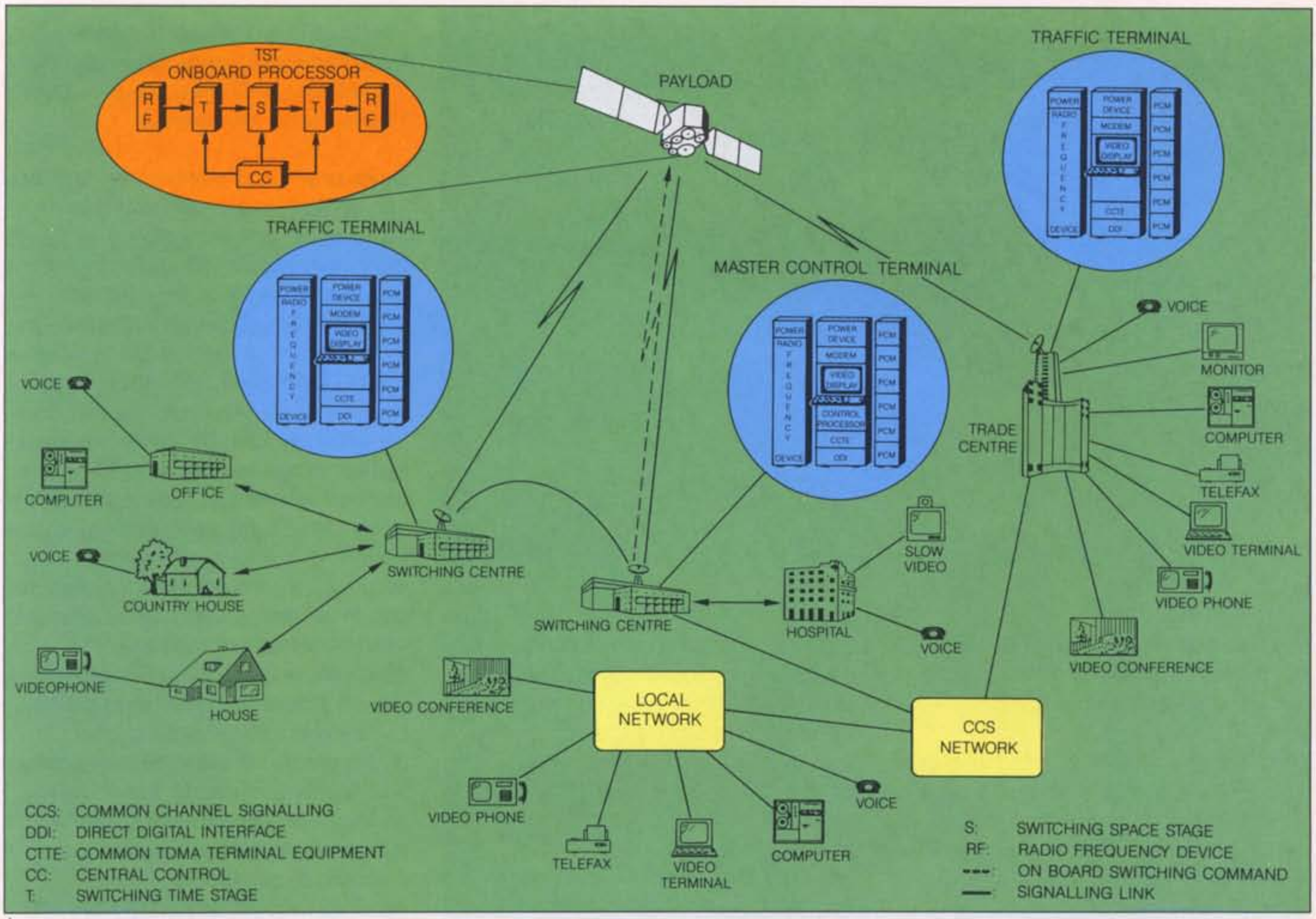
The mission objectives involve three distinct tasks: firstly, the detailed imaging and monitoring of Earth-surface features (ocean and land); secondly, the continuous monitoring of atmospheric conditions for weather observation and climatology; and finally observation of the kinematic and dynamic behaviour of the geoid and the Earth's crust.

After the first-generation satellites ERS-1 and ERS-2, mainly dedicated to ocean observation, further development of Synthetic Aperture Radars (SARs) into multi-polarisation, multi-frequency (L, C and X-band) systems is needed for all-weather imaging with the resolution required for land features through cloud cover from large platforms in polar orbits (Fig. 7). Larger phased antenna arrays for the lower frequency bands, and more efficient high-power amplifier tubes for the higher bands (Fig. 8) need to be developed, with special switches and phase shifters for multiple and steerable beams with wider swaths, to provide the required frequent coverage. Frequency-scanning techniques could also be used, particularly for microwave scatterometers,

Figure 4 — Advanced SS/TDMA with on-board time–space–time stages

Figure 5 — Multibeam Array Model (MAM) for a mobile communications payload operating at L-band

Figure 6 — Concept of an advanced satellite for mobile communications with inflatable space-rigidised reflectors



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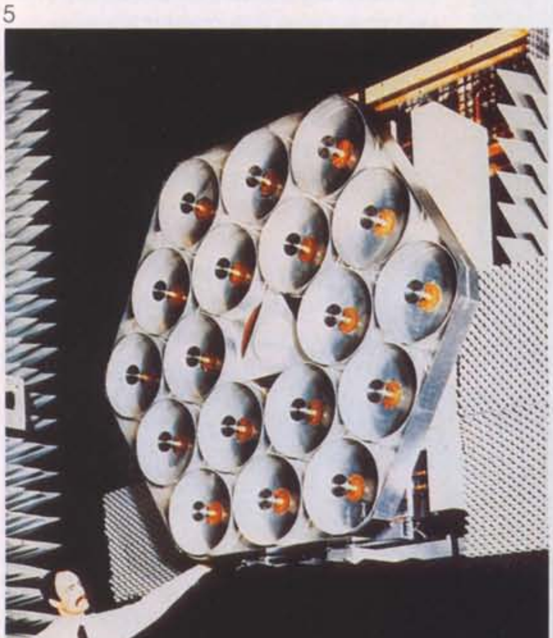

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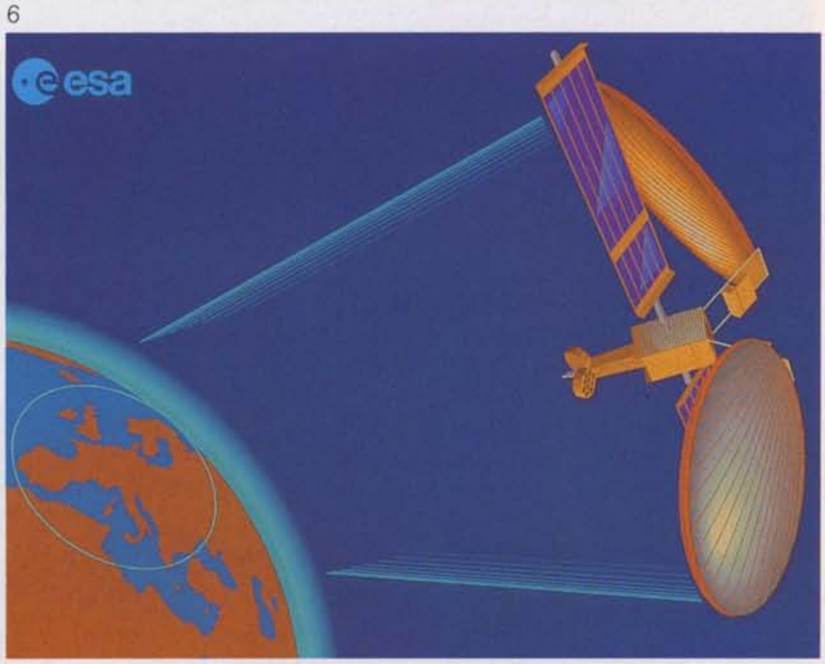


Figure 7 — The Polar Platform

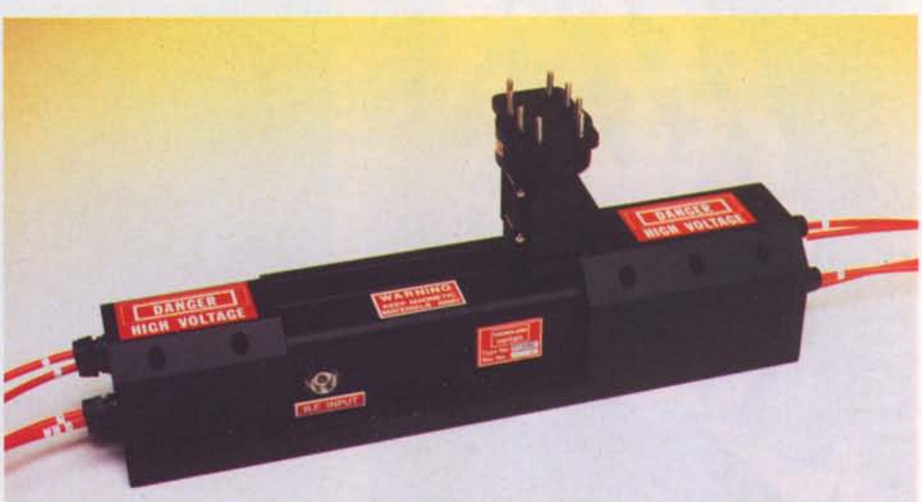


Figure 8 — Breadboard of a klystron high-power amplifier for an advanced Synthetic Aperture Radar (SAR)

which provide accurate global-scale information to oceanographers on sea state and surface winds.

Very accurate altimeters, using long pulse compression and reliable solid-state transmitters, will be used both for sea-state observation and geodetic measurements. For the latter, to obtain precise determination of the orbital position from the ground, even better satellite ranging accuracies (within a few centimetres) have to be achieved by the use of all-weather microwave systems like DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite) and PRARE (Precise Range and Range-rate Equipment).

For satellite-to-satellite tracking, from low Earth orbit to higher, more stable orbits, two-way measurements of range and range rate could be made to the highest precision (microns per second) by using millimetre waves (60 GHz) with small phased-array antennas which would not require moving parts.

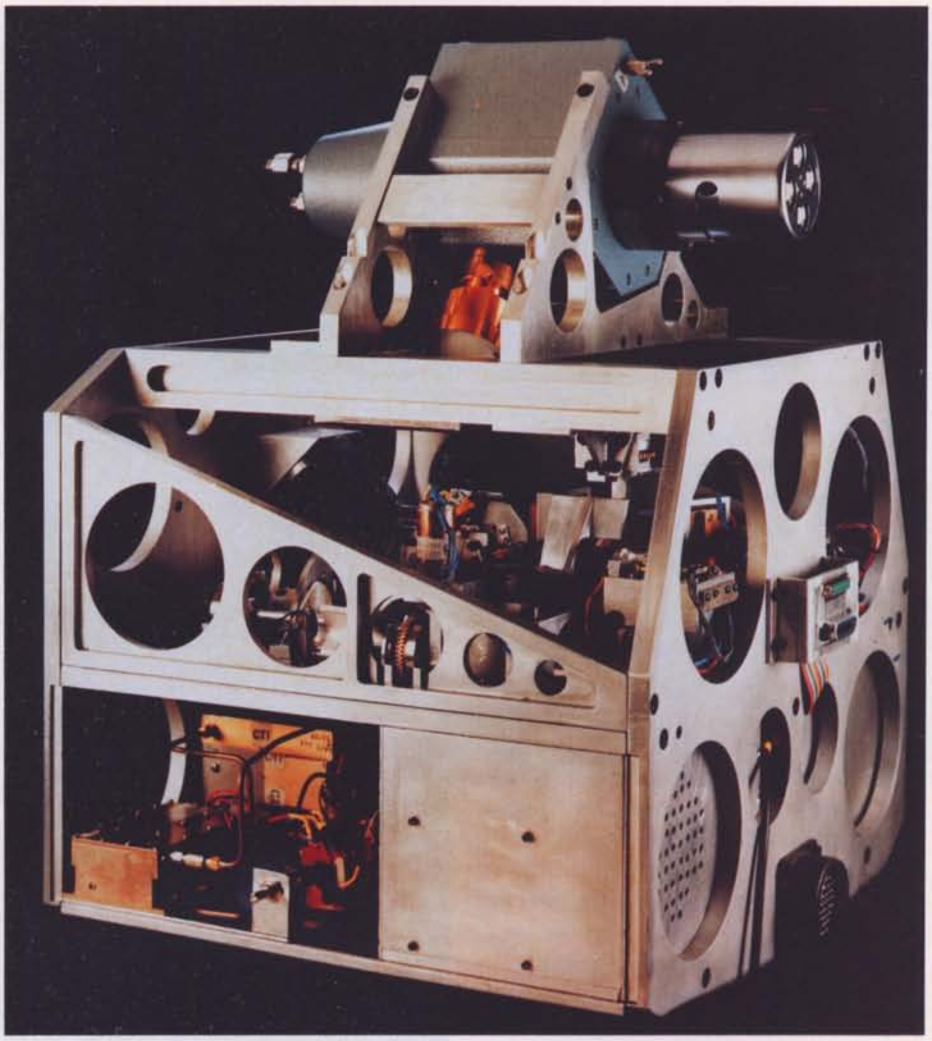
Imaging radiometry and atmospheric sounding from second-generation meteorological satellites will also make use of the millimetre and submillimetre bands for measuring the temperatures of the Earth's surface and for analysis of its atmosphere. The progression to shorter wavelengths is required to improve the spatial resolution by one order of magnitude (to a few km). Using tens of channels at different frequencies will provide spectral resolution for the sounding of atmospheric constituents and for surface thematic mapping (humidity, ice, snow coverage and types). To provide adequate integration times, pushbroom scanning techniques of the sort used for optical and infrared wavelengths, with arrays of receivers and feeds illuminating large, accurately manufactured reflectors, are also being introduced for microwaves.

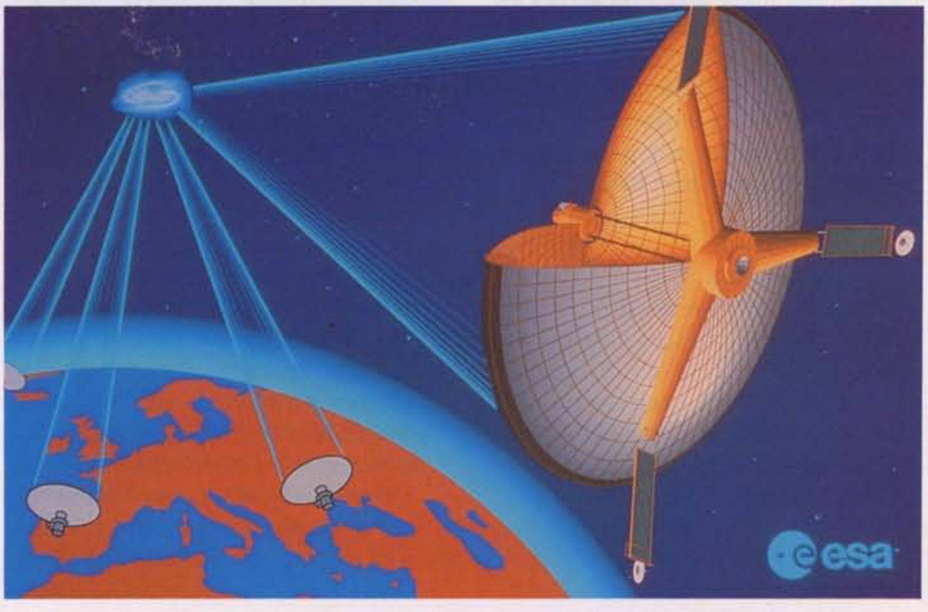
Deep-space and observatory facilities
The ultimate goal in this case is to make available the critical microwave technology needed for future scientific missions, in particular the 'Cornerstone Missions' of the Long-Term Plan outlined in the document 'Horizon 2000' (ESA Special Publication SP-1070).

For example, the FIRST submillimetre Earth-orbiting telescope facilities will demand advances in large, accurate and highly stable lightweight reflectors (diameters of 8 m with better than 10 μm accuracy), mixers and detectors with cryogenic cooling, detectors and tunable local oscillators for heterodyne spectroscopy in the 1000 GHz domain (Fig. 9). Planetary missions, on the other hand, demand technological developments in communications, using new, higher frequencies, X- and perhaps Ka bands and extremely accurate or autonomous guidance, due to the large distances to be covered, the high velocities of travel, and entry into planetary atmospheres. For ultimate performance at Saturn- and Neptune-type ranges, deep-space communications require: the linking

Figure 9 — Breadboard of a heterodyne spectroscopy receiver for the 300–1000 GHz band

Figure 10 — Concept for a Very Long Baseline Interferometer (VLBI) using an orbiting radio-telescope





together of several 64 m Earth stations into 'interagency' arrays; maser low-noise amplifiers; sophisticated data/signal coding; and very accurate autonomous pointing of the probe's antennas.

Space science is also considered to be one of the strongest technology drivers for centimetric microwave development, with radar mapping and sounding of asteroids and other celestial bodies currently being studied. Spacecraft antenna reflectors for orbiting radio telescopes and Very Long Baseline Interferometers like Quasat (Fig. 10) are being pushed up to diameters of 20 m, with accuracies compatible with the reception of 22 GHz signals.

Microgravity utilisation

This theme is concerned with the facilities for conducting material- and life-sciences experiments in the microgravity environment of future Spacelab, Eureca or Space-Station/Columbus missions. The technical needs involve a very broad spectrum of disciplines, ranging from high-temperature furnaces to electrostatic and electromagnetic positioning devices.

In this context, microwaves and electron beams are used for heating purposes and to assist the formation of pure semiconductor crystals in low gravity. Non-intrusive sample monitoring could also be a new domain of application for millimetre waves, particularly when fully automatic operations are required.

Space platforms

The goal in this area is to prepare the technology needed for the space platforms of the future, in particular those Columbus elements that are envisaged as part of the In-Orbit Infrastructure of the 1990s.

For the enhanced Eureca, the Man-Tended Free Flyer and the Polar Platform, S-band telemetry and telecommanding will be used for the low-bit-rate links to ground, to the Shuttle and to the other elements of the Space

Station. The enhanced Eureca will also use the Ka band link via Olympus, with higher data rates and extended coverage.

The other free-flying platforms will be equipped with GPS terminals for accurate position determination and DRS terminals for very high-data-rate communications (up to 300 Mbit/s) compatible with both the US and European systems.

The Polar Platform, like the first-generation Earth-observation satellites, will also carry X-band transmitters for direct high-capacity links to ground stations.

It is intended that this infrastructure should ultimately provide a comprehensive and autonomous European capability. Tracking and the full 500 Mbit/s communication capacity will then be assured by the European DRS system, with global coverage. The 'growth technology' needed for the Columbus Advanced Operating Capability (AOC) and the techniques and tools required in the medium and longer term for the design and operation of other space platforms (Fig. 11) will need to be addressed. In view of the complexity of the payloads, many operating across the full microwave spectrum, electromagnetic compatibility testing and frequency coordination will become major design drivers, probably advancing the introduction of optical communications for the second-generation DRS.

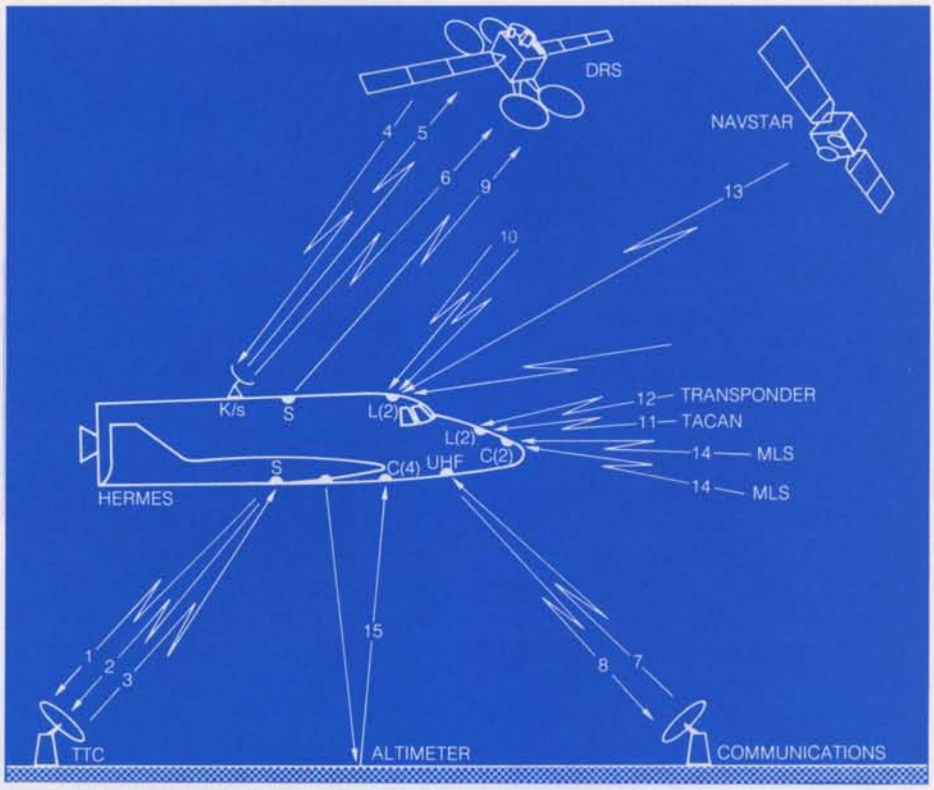
Figure 11 — Artist's impression of free-flying space platforms forming part of an Advanced Operating Capability (AOC)

In-orbit operations

This theme reflects the expected evolution of future missions involving a significant number of in-orbit operations after a spacecraft has been launched, whether by Ariane or by the US Space Shuttle. The four areas of technology currently covered within the theme are:

- 'Rendezvous and docking', where microwaves are to be used for guidance in long-range sensors, and millimetre waves for high-resolution compact radars and proximity sensors.
- 'In-orbit propulsion', where microwaves could be used in plasma and ionic propulsion.
- 'Robotics, telemanipulation and servicing', where millimetre waves can be used in proximity and position sensors. Lower frequencies, down to VHF, will provide the secure communications required for manned extra-vehicular activities.
- 'Large dimensions in space', involving joint operation of widely separated spacecraft to meet a variety of mission objectives, and with a need for very accurate relative ranging and navigation, e.g. for establishing very long interferometric baselines in space. Reliable microwave links with simple terminals could be used in competition with the more accurate optical ranging, since the latter calls for refined telescope pointing.

Figure 12 — Radio links for the Hermes spaceplane



Space transportation

The objectives here are to maintain an independent capability for Europe, based on the Ariane-launcher family, meeting the foreseeable increasing requirements of European and other users, and to remain competitive with other space-transportation systems, both existing and planned.

These goals will be achieved through the development of the more powerful Ariane-5 vehicle, able to deliver 21 t into low Earth orbit and with a 4.5 m diameter shroud allowing larger payloads to be launched (larger antennas in particular). Ariane-5 could also be the first launcher to rely on an S-band Data-Relay Satellite link for down-range telemetry and tracking.

Finally, the Hermes spaceplane is now being developed for manned transportation and orbital servicing based on Ariane-5 as a first stage, but with an autonomous landing capability. This will require a very safe, complete and integrated communications, navigation and landing instrumentation system exploiting the full electromagnetic spectrum, from the VHF of voice communications for astronauts in EVA and for landing, to the 27 GHz of the European DRS link. Some 15 radio links will be operated on Hermes (Fig. 12). Again frequency planning and electromagnetic compatibility will be major design drivers and testing tasks.

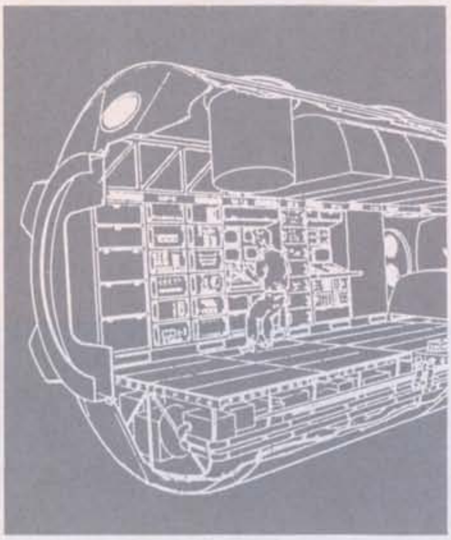
A totally new problem for European technologists will be the development of communications facilities, particularly antennas, compatible with the spaceplane's transonic aerodynamics and its reentry into the Earth's atmosphere from space.

Conclusion

The study and analysis of future missions show that microwaves, which are already a mature and well-proven technology for terrestrial applications, will have a very wide range of future space-based applications. Moreover, the technological advances currently being pursued can themselves create new mission opportunities.

Experience has shown that continuous and detailed interaction between those responsible for mission requirements, feasibility and definition studies, and those charged with technology development is essential to optimise the development cycle and to avoid wasting resources unnecessarily on technology that could turn out to be obsolete at the critical moment of need.

Even in cases where microwave technology may already have been widely used in a terrestrial system, in-orbit demonstrations and sometimes pre-qualification on experimental missions provided for in ESA's Long-Term Plan, will continue to be necessary to reduce the development and schedule risks for Europe's current and future space projects.



The Columbus System Baseline and Interfaces

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The current Columbus system baseline can be traced back to a number of Space-Station-linked studies funded by ESA during the period 1982–1984, plus nationally funded studies undertaken by Germany, Italy and the United Kingdom during the latter part of the same period. All were completed in the summer of 1984, shortly after the invitation of President Reagan to Europe and certain other countries to join the United States in an international Space-Station Programme.

This article reviews the evolution of the Columbus system baseline and describes the most significant changes introduced as a result of both the definition process itself and changes introduced into other major systems with which Columbus has major external interfaces.

Origins of the Columbus Programme

In 1982, with the Spacelab development programme nearing successful completion and NASA again actively studying the Space Station as the next logical step to the Space-Transportation System, ESA proposed a number of 'Phase-A' studies to define possible Spacelab follow-on programme options for Europe. The primary goals set for these studies were:
- to *identify* the potential European and international user needs for the 1990s and beyond
- to *propose* system concepts that would build on the manned-spaceflight experience gained through the Spacelab Programme
- to *explore* options involving continued cooperation with the United States in the frame of the proposed Space Station, but which would not exclude the potential for Europe to develop an autonomous space infrastructure in the longer term.

The major system-level studies undertaken by the Agency in response to the above goals were:
- a Spacelab Follow-on Development Study
- European User Aspect Studies
- an In-orbit Infrastructure Study
- a Manned Space-Station Study
- a Space-Station System Study.

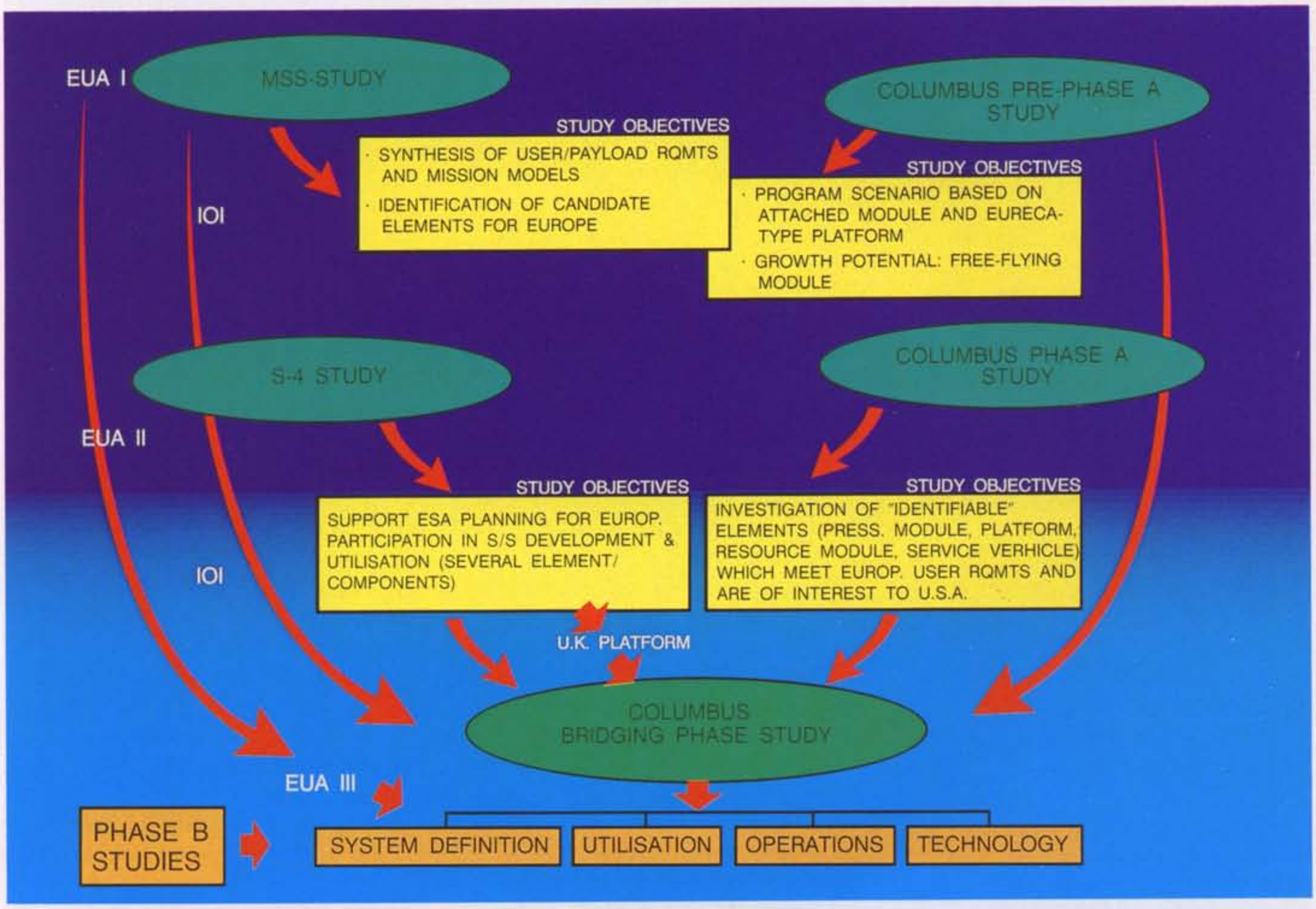
Germany and Italy also conducted the nationally funded Columbus Phase-A study with similar objectives to the ESA studies, but concentrating on a more specific scenario involving a further development of the Spacelab module for deployment in conjunction with the NASA Space Station, and development of an unmanned platform for either Space-Station co-orbiting missions or polar-orbiting missions. The United Kingdom initiated a nationally funded study to develop further the concept of the serviceable polar platform already studied in the framework of the ESA Space-Station System Study.

The parallel flows and relationships of all of the above studies are shown in Figure 1, together with their input paths to the current Columbus Phase-B studies.

Initiation of the Columbus Programme

The Columbus Preparatory Programme (Phase-B) was initiated immediately after the Meeting of the ESA Council at Ministerial Level in January 1985 in Rome. An inter-Agency Memorandum of Understanding (MOU) was finalised and approved by ESA and NASA to cover co-operative aspects and mutual exchange of data during the definition phases of the Columbus and Space-Station Programmes, which were planned to be conducted in parallel. Similar agreements were signed between NASA and the other international partners, Canada and Japan. The ESA/NASA Memorandum of Understanding (MOU) specifically identified a key milestone in March 1986, about half way through the planned two-year parallel definition phases, at which the two Agencies would mutually agree, in the form of a Programme-Level Agreement, the Columbus Flight Elements to be carried forward for the remainder of the cooperative definition phase.

Figure 1 — Major system-level studies undertaken in the period 1982—1987



The existence of this inter-Agency milestone was one of the primary reasons for dividing the Columbus Phase-B definition studies into two separate phases, Phase-B1 being planned to run from May 1985 to March 1986, and Phase-B2 from April 1986 to March 1987. Due primarily to the fact that the ESA/NASA Programme-Level Agreement was not achieved until the summer of 1986, Phase-B1 was eventually extended until July 1986, while Phase-B2 did not start until November 1986.

Initial system baseline and interfaces
The system baseline, as identified at the start of Phase-B1, was established following completion of the Columbus 'Bridging Phase', conducted in late 1984/early 1985 to harmonise the results and recommendations arising from the various ESA and national Phase-A studies referred to above. The Bridging Phase also included an assessment of the NASA Space-Station System Requirements and Reference Configuration, as documented in the NASA Space-Station Phase-B Request for Proposal (RFP).

The Phase-B1 Invitation to Tender (ITT) was issued to European industry in February 1985 and documented the Columbus system baseline in the form of a set of System Requirements, supported by Reference Configurations for the Columbus Flight Elements, a Reference Operations Concept and Reference Payload Model Missions. The Reference Configurations and Operations Concept were issued as 'points of departure' for the system-definition studies, and the Payload Model Missions as a set of references against which the definition of the Flight Elements was to be matured in terms of systems sizing, capabilities and performances.

System requirements
The System Requirements consisted of 'US-sourced' requirements, taken from the NASA Phase-B RFP, and 'Columbus-sourced' requirements taken from the ESA and national Phase-A study results. At the start of Phase-B1, a number of key system driving parameters such as launcher performance, module pressure level and primary power type/voltage, were not specified in the requirements and were documented in the form of system options to be traded-off during the phase. It was recognised that several

of these could only be finalised in conjunction with the ongoing NASA Space-Station definition studies.

The Flight Elements included as a part of the system baseline for Phase-B1 were identified as:

- A *Pressurised Module*, based on the Spacelab Module, to be integrated into, or attached to, the NASA Space-Station manned base. Its ability to perform unmanned free-flying missions in conjunction with the Resource Module was to be assessed.
- A *Resource Module,* to provide the requisite resources and services for the Pressurised Module when in its free-flying mission mode.
- Free-flying unmanned *Platforms,* co-orbiting with the manned base, and in polar orbit.
- An unmanned *Service Vehicle* to support the free-flying Platforms. Growth to a manned Service Vehicle was to be assessed.

The Pressurised Module, when flying in its unmanned free-flying mode in conjunction with the Resource Module, was assigned a separate identity — the Columbus *Man-Tended Free-Flyer* (MTFF).

The System Requirements identified the NASA Space Transportation System (NSTS) as the reference launch system for all Columbus Flight Elements, with the added requirement to assess their compatibility with Ariane-5 as an alternative launch vehicle. The Tracking and Data-Relay Satellite System (TDRSS) was specified as the primary communications and data-link medium for the Flight Elements.

Reference Configurations

Reference Configurations, including configuration options together with major performance parameters, were identified for each of the above Flight Elements, with the exception of the Resource Module, which had not reached a sufficient level of maturity at the start of the phase. The main configuration options addressed in the system baseline were as follows:

Pressurised Module

Two configuration options were identified which differed only in the docking-port arrangement, one option having radial ports to enable it to be fully integrated within the 'module racetrack' of the NASA Space-Station manned-base Reference Configuration, the other having axial ports to allow for simple end attachment to one of the Space-Station manned-base nodes. The diameter of the module was fixed at the Spacelab Module diameter, but its length was not fixed, the equivalents of three of four Spacelab segments being the primary candidates. A 1 g internal architecture layout (i.e. floor/ceiling) was defined as the reference, with other internal layouts to be studied as options. The module internal pressure was not fixed, but was to be finalised as a function of the eventual pressure level selected for the Space-Station manned base. The power available to the module from the Space Station was assumed to be 30 kW for systems and payload combined, the power type (AC/DC) and voltage level (120—150 V) being the subject of Space-Station trade-off studies. A nominal crew of three was specified as the reference for system and payload operations.

Polar/Co-orbiting Platforms

Two basic configuration options were identified, the first representing an integrated configuration with platform resources and services distributed and optimised for the polar-platform mission, the second being a clearly modular approach with all basic resources and services concentrated in a 'utilities or resource module'; a second separable module — the payload carrier — was to serve as the payload mounting area. These two configuration options were included in the Phase-B1 system baseline to establish the feasibility, or otherwise, of developing a single basic configuration for the co-orbiting and polar-platform missions, even though the mission requirements identified for them were significantly different in terms of platform sizing and performance parameters. The reference orbital parameters were specified as 500 km/28.5° for the co-orbiting platform and 700 km/98.2° for the polar platform. For the polar-platform case, both 'morning' and 'afternoon' orbits were identified as candidate mission options. The platform overall power sizing was set at 20 kW.

Service Vehicle

Although the system baseline for Phase-B1 addressed primarily the unmanned Service Vehicle for servicing the platforms, a manned configuration option was also included in the Reference Configurations to cover a possible servicing scenario for the Pressurised Module in its free-flying mode and to verify the feasibility, or otherwise, of developing a manned Service Vehicle as a growth version of the unmanned Service Vehicle.

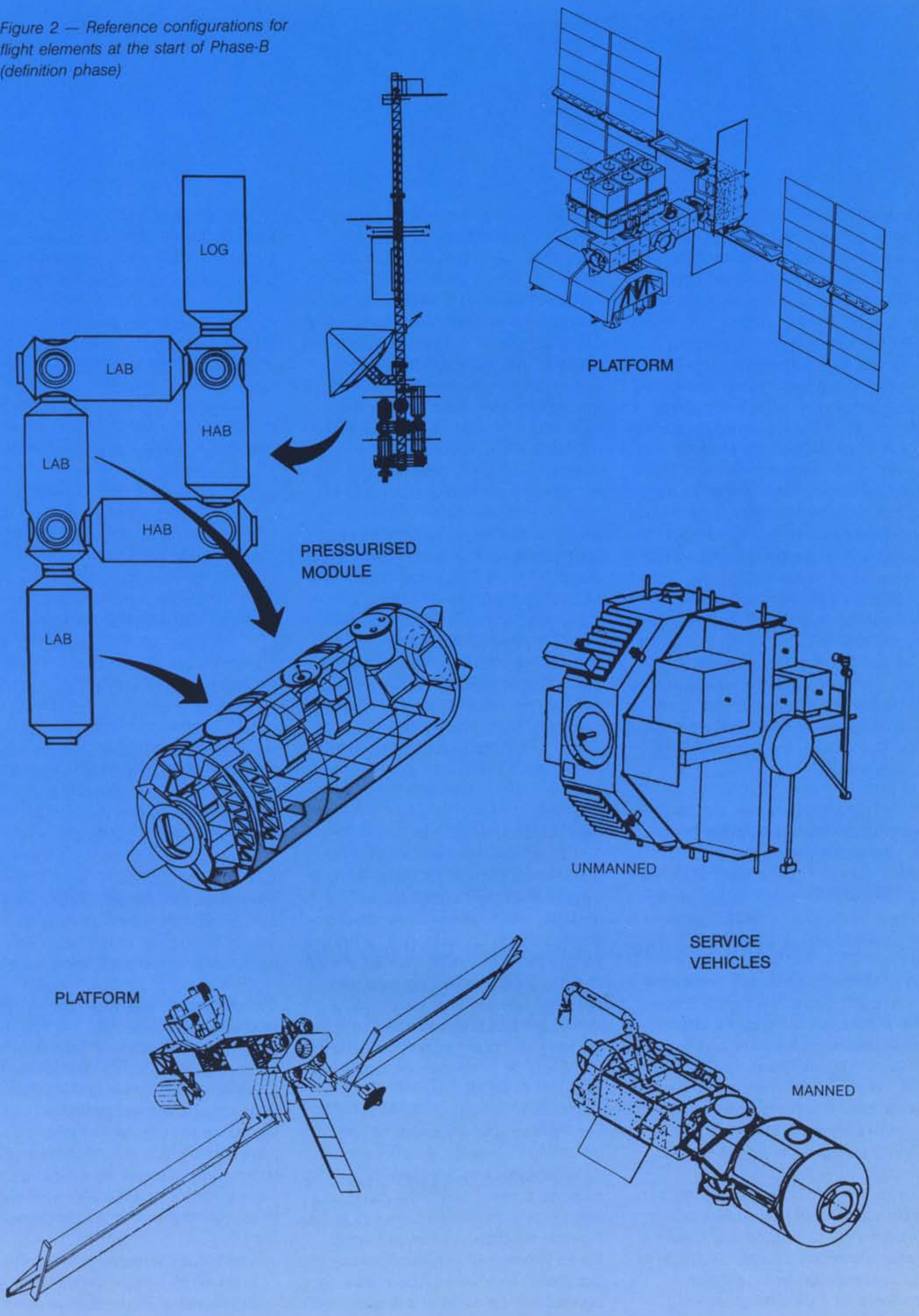
The Reference Configurations identified for the start of Phase-B1 are shown in Figure 2.

Reference Operations Concept

The Reference Operations Concept addressed typical operational scenarios for the Columbus Flight Elements, based on the principle of operational control from Europe. One of the primary tasks identified for Phase-B1 ground-segment studies was to develop these scenarios in conjunction with NASA to establish a top-level operational concept for the combined operations of Columbus and the Space Station. The Reference Operations Concept also specified the launch and servicing scenarios and options to be used in support of the definition of each of the Flight Elements. These were specified as follows:

Pressurised Module: To be launched directly to the Space Station by the NSTS and to be attached to, or integrated into, the manned base by the Orbiter Remote

Figure 2 — Reference configurations for flight elements at the start of Phase-B (definition phase)



Manipulator System (RMS), station manipulator and crew Extra Vehicular Activity (EVA). Subsequent servicing was to be at the Space Station, using the NSTS 90-day logistics cycle for up- and down-loads. Primary servicing mode was to be by crew Intra-Vehicular Activity (IVA), with station-manipulator/crew-EVA for external servicing. This scenario was also identified for the unmanned free-flying mode of the Pressurised Module (see also under Resource Module).

Polar Platform: To be launched by the NSTS to an intermediate orbit for deployment and on-orbit assembly by the Orbiter RMS and crew EVA. After initial transfer up to operational orbit, subsequent servicing was to be every two years by 'fly-down' to the NSTS, or alternatively in-situ by 'fly-up' of the ground-based Service Vehicle, deployed/retrieved by the NSTS. Primary servicing for the NSTS case was to be by the Orbiter RMS plus crew EVA, and for the Service-Vehicle case by robotics.

Co-orbiting Platform: To be launched by the NSTS directly to the Space Station's orbit for deployment and in-orbit assembly by the Orbiter RMS and crew EVA. Subsequent servicing was to be every three to six months by 'fly-back' to the Space Station or alternatively in-situ by the NSTS or the Service Vehicle, based at the Space Station in this case. Primary servicing mode for the Space-Station case was to be by the station manipulator and crew EVA, and for the NSTS case by the Orbiter RMS and crew EVA. The servicing mode for the Service-Vehicle case was not defined, pending eventual selection of the unmanned or manned configuration for this vehicle.

Service Vehicle: To be launched by the NSTS, either to an intermediate orbit for deployment and initiation of a Polar-Platform servicing mission, or directly to the Space Station for berthing, in readiness for a co-orbiting servicing mission. For the first case, the Service Vehicle was to be returned to ground for servicing on completion of each Columbus servicing mission after rendevous with, and retrieval by, the NSTS. For the second case, Service-Vehicle servicing was to be performed at the Space-Station manned base between missions. The servicing mode for the ground-based case was to be normal ground-crew intervention and for the Space-Station-based case by the station manipulator and crew IVA/EVA, depending on the Service-Vehicle configuration eventually selected.

Resource Module: To be launched by NSTS directly to the Space Station for assembly onto the attached Pressurised Module by the Orbiter RMS, station manipulator and crew EVA, to make up the MTFF flight configuration. Subsequent servicing was to be at the Space Station between unmanned free-flying MTFF missions (three months to one year). The primary servicing mode was to be by Station manipulator and crew EVA.

Payload Model Missions

The system baseline, as defined in the System Requirements for Phase-B1, was completed by the Payload Model Missions, which identified the reference payload sets to be enveloped by the configurations and performances of each of the Flight Elements. These payload sets were selected from the European User Aspects (EUA) database and were the same as those that had been input by ESA to the NASA Space-Station-User Database (SSUDB).

The Payload Model Missions reflected the strong European user interest in the microgravity-related disciplines of materials science, fluid physics and, to a lesser extent, life sciences, as well as the high interest shown in Europe towards the Earth-observation/meteorology disciplines. They were grouped into payload sets per Columbus Flight Element:

Pressurised Module

MAT-110	Materials Research Laboratory
MAT-120	Microgravity (crew-interactive)
LIF-111	General-Purpose LIF Facility

Also identified for the Pressurised Module were a group of technology experiments: TOS-235, -236, -241 and -244.

Co-orbiting Platform

MAT-130	Automated Materials Processing
LIF-310	Biology
LIF-312	Bio-Processing

Polar Platform

EOB-310	Morning-Platform Earth-Observation Payload
EOB-410	Afternoon-Platform Earth-Observation Payload
SCN-310	Mobile Radio 1
SCN-410	Mobile Radio 2
LIF-313	Biology

No specific payload sets were identified for the Pressurised Module in its free-flying mode, pending better definition of this flight configuration and further development of the associated operational scenario. Derivatives of the payload sets identified for the Pressurised Module were clearly seen as the primary candidates, particularly in view of the implied 'mixed mode' of operation for this Flight Element.

Current system baseline and interfaces

As a result of the trade-off studies carried out during Phase-B1, the outcome of the ESA/NASA Programme-Level Agreement, and programmatic adjustments introduced to meet the overall programme funding envelope, a number of significant changes were introduced into the system baseline prior to entering Phase-B2. The most important changes are:

- The Service Vehicle has been dropped as a Flight Element during the course of Phase-B1, due primarily to the complexity of the servicing scenarios involving this vehicle and the fact that alternative servicing solutions were available for each of the remaining Columbus Flight Elements.

- The original concept of a 'common' bus configuration for the Co-orbiting and Polar Platforms has been dropped and all effort on a large Co-orbiting Platform has been terminated. The Polar Platform has been reduced in size to match the mission requirements better.
- An enhanced version of the Eureca platform (Eureca-B) has been introduced as a programme option for a small Co-orbiting Platform, in place of the original large Co-orbiting Platform. The Reference Configuration for this is shown in Figure 3*.
- The original concept of a mixed attached/free-flying mission scenario for the Pressurised Module has been dropped and a second, smaller, Pressurised Module has been introduced into the programme, dedicated to the Man-Tended Free-Flyer (MTFF). The integrated configuration option for the Pressurised Module has been dropped as it is no longer required to be compatible with the Space-Station manned-base Reference Configuration, and the length of the attached Pressurised Module has been fixed at the equivalent of four Spacelab segments. The module internal pressure has been fixed at 1 atm and the internal architecture is based on a 1 g layout.
- A dedicated MTFF Reference Configuration has been introduced into the system baseline and a Reference Mission has been established for this with the following payloads:
  MAT-140 Material-Science Payload
  LIF-141 Life-Science Payload (Biology)
- Ariane-5 has replaced the NSTS as the specified launch vehicle for the Polar Platform and has been baselined for launch of the dedicated MTFF flight configuration.
- Hermes has been introduced as the primary servicing vehicle for the Polar Platform and as a second servicing mode for the MTFF (the first being at the Space Station).
- The European Data-Relay Satellite (EDRS) has been introduced into the system baseline, in addition to TDRSS, as a communications and data-transfer medium for the Columbus free-flying flight configurations.

With Phase-B2 now almost completed, the system baseline and its associated external system interfaces are still being updated as a result of the continuing definition process and changes introduced into the Space-Station, Ariane and Hermes programmes. In particular, configuration options have been reopened for the Polar Platform and the MTFF in response to the major requirements changes introduced after completion of Phase-B1, and the more recent changes in Ariane-5 and Hermes configurations/performances. The Columbus Preparatory Programme schedule has been extended up to the end of 1987 to allow sufficient time to complete definition of the system in conjunction with the maturing understanding of the key external interfaces. The current status is described below.

Systems Requirements

The Systems Requirements continue to be updated as the Columbus system becomes more mature. There are still a large number of items to be finalised in several key areas, many of which are related to the major external interfaces and the associated interaction of the various major programmes currently under parallel definition. There has been no significant dialogue with NASA for some time on harmonising some of the key system requirements, such as power, life-support systems and standard payload interfaces. These areas need to be worked on extensively prior to entering into the development phase under a co-operative programme agreement.

The key payload parameters of mass and power for each of the Columbus flight configurations are becoming stabilised around the values shown in the table below.

Key payload mass and power parameters

Attached Pressurised Module	
Payload power	10 kW average
Payload mass	0—3000 kg at launch (NSTS-limited) up to 10 000 kg operational
Polar Platform	
Payload power	3.0 kW daylight average/2.3 kW eclipse average
Payload mass	2000 kg at launch (launch-vehicle-performance dependent)
Man-Tended Free-Flyer	
Payload power	5 kW average/
Payload mass	2000 kg at launch
Enhanced Eureca	
Payload power	1 kW average
Payload mass	1000 kg

* See article on page 24 of this issue

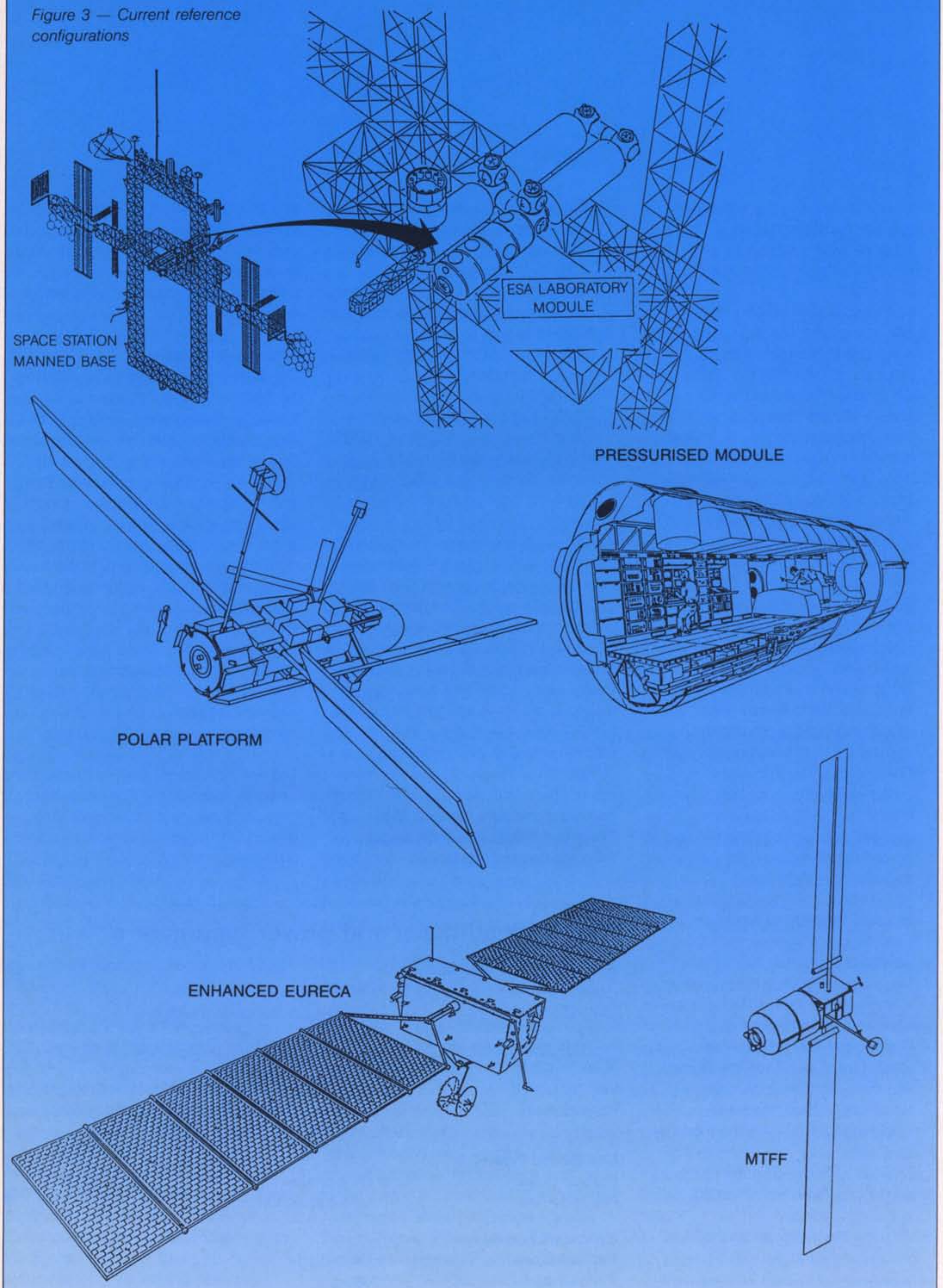


Figure 3 — Current reference configurations

Reference Configurations

Attached Pressurised Module

The Reference Configuration for the Attached Pressurised Module remains basically unchanged in its general sizing and accommodations. The baseline for the primary structure, however, is currently being proposed to be changed to an all-welded construction, rather than the separate-segment approach used previously.

Man-Tended Free-Flyer (MTFF)

The Reference Configuration established for the MTFF prior to the start of Phase-B2 is still maturing, with configuration options yet to be finalised in conjunction with the final selection of the Polar- Platform flight configuration. The current status is as follows:

- Pressurised Module: Remains essentially unchanged from that established prior to the start of Phase-B2. An all-welded construction for the primary structure is now being proposed instead of the two-segment approach previously used. This is in line with the change proposed for the Attached Pressurised Module.
- Resource Module: Two configuration options for the Resource Module are currently retained:
  1. A dedicated Resource Module, optimised for the MTFF mission.
  2. A common-core Resource Module for application to the MTFF and the Polar-Platform missions.

Both of the above configurations are based on an active thermal-control system, the main difference being in the distribution of subsystem functions between the Resource Module and the Pressurised Module (option 1) or Polar-Platform Payload Carrier (option 2). Both options have the capability of access to the TDRSS and EDRS. The selection of one or other configuration will be made in conjunction with the selection of the Polar-Platform configuration.

Polar Platform

The Reference Configuration for the Polar Platform currently includes three configuration options:

1. A dedicated platform configuration, matched to the Hermes servicing capability and with a design life of 12 yr. This configuration employs a passive thermal system design and is compatible with NSTS servicing, which would be required to extend the platform's operational life beyond 8 yr due to the limited Hermes upload capability.
2. A dedicated platform configuration, matched to the NSTS servicing capability, with a design life of 30 yr. This configuration also employs a passive thermal-control system and assumes a servicing interval of 3 yr.
3. A platform configuration based on the use of the common core Resource Module, as also used for the Man-Tended Free-Flyer. This configuration uses the active thermal-control system of the Resource Module.

All of the above configurations meet the key payload parameters identified in the accompanying table, and include the ability to access both the TDRSS and EDRS. It is currently planned to select the baseline configuration no later than May/June 1987, prior to entering the final phase of the preliminary design activity.

Co-orbiting Platform

The Reference Configuration for the enhanced Eureca remains essentially unchanged.

In refining the above Reference Configurations (Fig. 3) during the current study phase, a considerable level of subsystem commonality has been introduced across the Pressurised Module, Resource Module and Polar-Platform Flight Elements. This includes common solar arrays (including deployment mechanisms and masts), common communication subsystem hardware (including antenna masts), common onboard data-management and guidance, navigation and control hardware, and common engines.

Reference Operations Concept

The Reference Operations Concept has been further updated to reflect Ariane-5 launch operations, the Hermes servicing missions and use of the EDRS. The current reference scenarios per flight configuration are as follows:

Attached Pressurised Module: To be launched by the NSTS directly to the Space Station and docked by the NSTS Orbiter/Space-Station manipulator systems, with crew EVA as a backup, all servicing and payload exchange to be accomplished via the 90 d NSTS logistics cycle. Servicing mode is IVA for payloads and internal systems and station manipulator/crew EVA for external equipment.

Man-Tended Free-Flyer: To be launched by a single Ariane-5 vehicle into an intermediate ±450 km/28° orbit with an initial payload of up to 2000 kg. Automatic deployment and final positioning to initiate a 'boomerang' trajectory for optimum microgravity conditions and to facilitate subsequent rendezvous with the Space Station or Hermes for servicing. Servicing and payload exchange to be accomplished whilst docked to Hermes or the Space Station at a nominal service interval of 180 d. Servicing mode is by IVA for all payloads and internally mounted subsystems and by the Hermes or Space-Station manipulator systems plus crew EVA for externally mounted equipment.

Polar Platform: To be launched by a single Ariane-5 into an intermediate orbit with an initial payload of 2000 kg. Automatic deployment followed by transfer to its operational Sun-synchronous 'morning' orbit at ±850 km under its own propulsion. Servicing and payload exchange to be accomplished by fly-down to rendezvous with either Hermes or the NSTS at a nominal service interval of four or three years, respectively. Servicing mode is by the Hermes or NSTS Orbiter manipulator systems plus crew EVA.

Pressurised Module Reference Mission

		No. of racks required	No. of racks accommodated
MAT-110	Work bench	3	2
	Metallurgy laboratory	5	4
	Fluid science laboratory	5	4
	Crystal laboratory	5	4
	Containerless processing lab.	2	2
	Dedicated experiment lab.	1	1
LIF-111	Work bench	3	—
	Biochem./biol. analysis	3	3
	Incubator	2	2
	Cooler freezer	2	2
	Bioprocessing facility	3	2
	Human facility	3	3
	Gravit. biol. facility	3	3
	Animal research facility	1	1
	Animal holding facility	2	—
	Centrifuge	4	—
Storage	Habitation/station equipmt.	18	13
	Category-III*	12	4
Subsystems	Subfloor equipment	15	15
	Crew work station	8	8
	Safe haven	2	2
	Scientific airlock	3	3
	Viewport access	2	2
		106	80

* Allocation of Category-III storage (experiment-specific storage) is far below what is really required. Assumption is that storage space equivalent to volume of 8—10 racks will be made available in the Station nodes or in the Logisitic Module.

Man-Tended Free-Flyer Reference Mission

		No. of racks required	No. of racks accommodated
MAT-140	Solution growth	1	1
	Vapour growth	1	1
	Liquid pH epitaxy	1	1
	Flux growth	1	1
	Travelling solvent	2	2
	Gradient furnace	2	2
	Containerless processing	2	2
	Thermophysics properties	1	1
	Critical point facility	1	1
	Cont. flow facility	1	1
	Transport properties	1	1
LIF-141	Protein crystal growth	1	1
	Gravit. biol. lab.	2	2
	CELSS test facility	2	2
	Radiation biol. exp.	*	—
	Aquarack	1	1
	Biotechnology facility	3	3
TOS-216	Techno. exposure facility	*	—
Subsystems		15	15
Spares			2
		38	40

* Potential externally attached payload.

Polar Platform Reference Mission

Core payloads	Mass (kg)*	Heritage
Advanced Very-High-Resolution Radiometer (AVHRR)	30	Advanced Tiros-N (NOAA-K,L,M)
High-Resolution Infrared Radiation Sounder (HIRS)	40	Advanced Tiros-N (NOAA-K,L,M)
Advanced Microwave Sounding Unit (AMSU)	100	Advanced Tiros-N (NOAA-K,L,M)
IR Limb Sounder	170	RAL CIR study
Scatterometer	250	Columbus payload study
Radar Altimeter	100	ERS-1
Synthetic Aperture Radar (SAR)	650	Columbus payload study
Advanced Microwave Sounding Unit (ATSR)	30	ERS-1
Imaging Spectrometer (MODIS T)	70	US studies
Passive Microwave Imager	240	Columbus payload study
	1700	
Additional Payloads		
ATLID	145	ESTEC instrument concept
Microwave Limb Sounder	167	Microwave Atmospheric Sounder (MAS) (Germany & Switzerland)
Conical Scan Radiometer	50	CSR Study (Germany)
Argos	100	Advanced Tiros-N (NOAA-K,L,M)
Search and Rescue	40	Advanced Tiros-N (NOAA-K,L,M)
	502	

* The above masses for the instruments only include a simple mounting plate for interfacing. Any additional mounting structures needed are considered to be part of the platform.

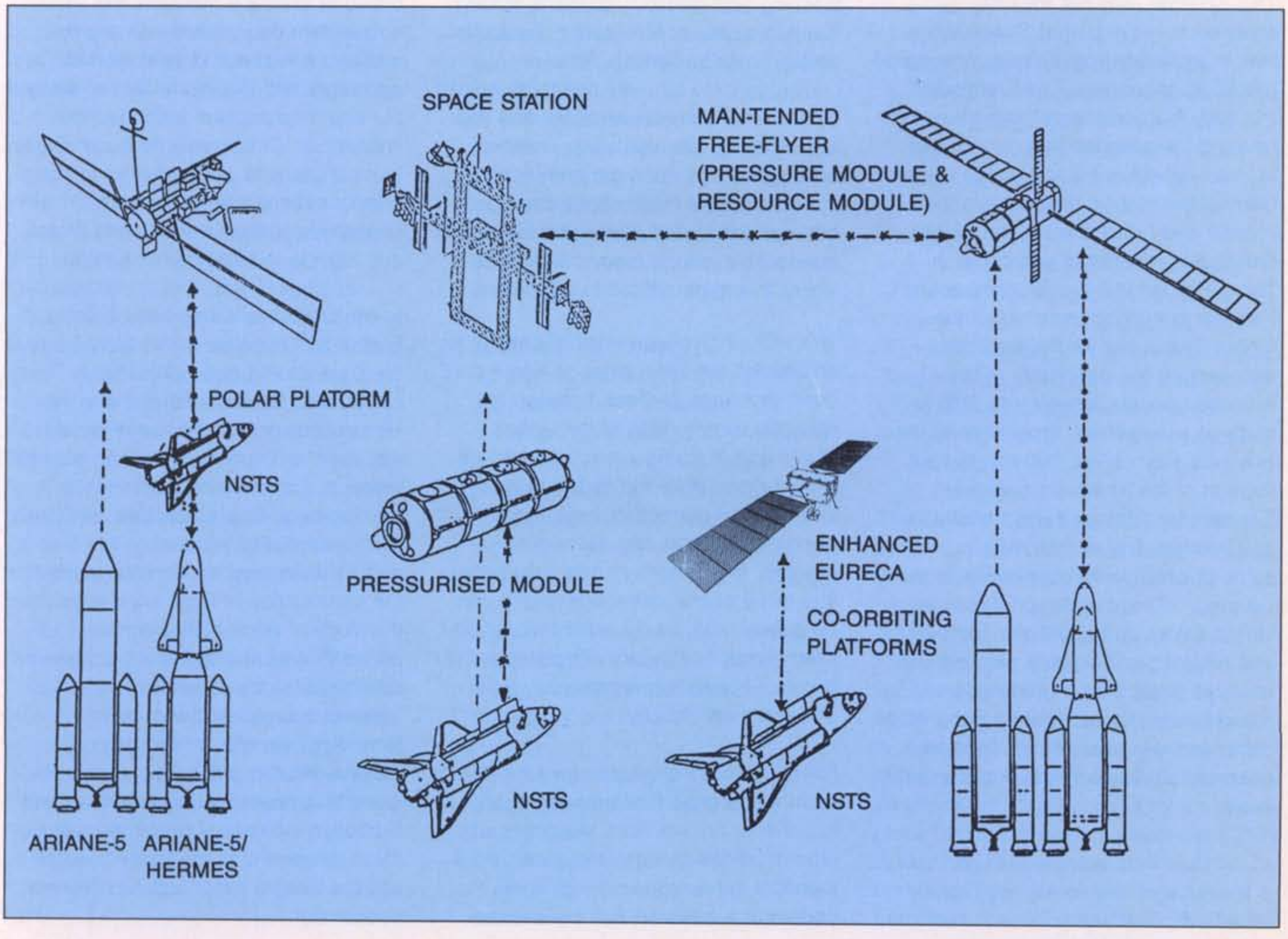
Figure 4 — Typical launch/servicing scenarios

Enhanced Eureca: To be launched by NSTS as a partial cargo into an intermediate orbit with a payload complement of 1000 kg. Removal from the Orbiter cargo bay by the Orbiter manipulator system, followed by automatic deployment and initiation of required trajectory to meet the specific mission needs. Rendezvous with the NSTS after a nominal mission period of one year plus for retrieval and return to Earth for servicing and ground processing for the next mission cycle. Typical launch and servicing scenarios are shown in Figure 4.

Payload Model Missions
The Payload Model Missions have now been significantly updated as a result of the ongoing Columbus Utilisation studies and specific user discipline studies. The current payload references used for the ongoing system-definition process are contained in the Model Payloads and Reference Missions document. The actual Reference Missions being used as inputs for the payload-accommodation aspects of the Pressurised Module, the Polar Platform and the Man-Tended Free-Flyer are summarised in the tables on the facing page.

The Reference Mission currently under study for the enhanced Eureca platform is SPA-410, the GRASP facility. This facility is representative of a number of medium-sized astronomical and astrophysical observations.

Conclusions
The definition process for the Columbus system is now reaching a critical stage, with convergence to a specific set of Flight-Element configurations a high-priority objective to allow the depth of definition required to enter the development phase of the programme. In several areas, the definition of the external interfaces to other major systems under parallel definition is not yet very mature and requires special emphasis. The studies performed to date have created a very comprehensive database, which will ease the task of convergence once major programme decisions are made.



Cooperation Between Europe and the United States in Space*

R. Lüst, Director General, European Space Agency

Introduction

I should like to express my sincere thanks for being invited to present this Fulbright 40th Anniversary Lecture. I regard this as a great honour as well as a particular pleasure, having myself been a Fulbright scholar in the United States 32 years ago.

This, however, was not my first experience in the United States. When I flew in yesterday from France, where ESA has its Headquarters, I was reminded that forty-four years ago I was on a ship heading for a French harbour. I never actually arrived in France as the vessel, a German submarine, was sunk in the Atlantic and I ended up in the United States at a prisoner of war camp in Texas. Fenced in there for three years, I had little chance to learn about the United States, but for the first time I experienced the generosity of the American people, since I was able to study at a 'university', organised by the prisoners themselves, but with the full support of the American authorities. Essential for this was the possibility to buy mathematics and physics text books, some of which were even available in German, having been reprinted in the United States during the war. In 1946 I was returned to Germany, where I received credit from the education authorities for my study time in the POW camp and was thus able to finish my university studies within two and a half years.

* The Fulbright 40th Anniversary Lecture, 6 April 1987, Washington DC

However, I became familiar with the way of life in the United States and with its Universities when I was here as a Fulbright Fellow in 1955 and 1956, at the Enrico Fermi Institute of the University of Chicago, and at the Astronomical Observatory of Princeton University. After this very fruitful Fulbright Fellowship, I was lucky enough to be given longer teaching and research positions at New York University, at MIT, and in particular several times at Caltech. As a consequence, I am very much influenced by the American academic life and your way of doing research work. Another consequence is that I am convinced of the necessity of close cooperation between the United States and Europe in science, but also in many other areas where it is more difficult to cooperate.

This lecture gives me another chance to emphasise the importance of a free and open exchange of views between the scientific communities of the United States and of Europe. It is true, and we should never deny the fact, that we live in a world of conflicting, or at least divergent, political and economic interests. But in spite of that, I do believe that many of our present problems can be solved more easily when there is an international community of scientists and scholars free to follow common goals and common objectives.

For two and a half years now I have been responsible for European space activities, a field of work in which I was already involved during the sixties. I will therefore concentrate my lecture on the cooperation between Europe and the United States in the area of space research and technology.

Space science is probably the most suitable field in which so many groups from US universities carry out research work directly with groups from European universities and institutes, develop joint experiments, and share the data obtained in space. However, this cooperation can serve as an example and as an indicator of how we can cooperate not only in the field of science, but also in projects of technological importance. Of course, it is much simpler in most cases to work together in basic science: this is true not only for endeavours between the United States and Europe, but also within Europe.

In the same way as we have to learn in Europe to cooperate in the technological area, we should also not exclude cooperation between Europe and the United States on certain large projects that have an impact not only on scientific research, but also on technological development. Space activities are one such area, fusion research is another, and I should also mention the example of the construction of large accelerators for the study of elementary particles. I fully realise that technology is a much more sensitive area for cooperation and that one has to look into the question of technology transfer with respect to national security, as well as economic competition between the American and European industry. However, sometimes these issues are all too easily brought into the foreground in order to prevent cooperation.

The principles of European/United States cooperation in space

The relationship between Europe and the United States in their cooperative efforts in space can be characterised by three periods:

1. the tutorship of Europe by the United States.
2. Europe as the junior partner of the United States.
3. Partnership and competition between Europe and the United States.

These phases of cooperation between Europe and the United States can also be seen in other areas of science, such as high-energy and elementary-particle physics or plasma physics. In space activities, the first period started at the beginning of the sixties and continued until the beginning of the seventies; the second period lasted until the beginning of the mid-eighties; and we have now entered the third period.

What have been the aims for this cooperation between the United States and Europe? Of course, every single European State, and later Europe as a whole, gladly accepted the help offered by the United States, through NASA, for their first steps into space. For the countries initially approached, such as the United Kingdom, France, the Federal Republic of Germany and Italy, it was the most efficient means of building up capabilities and capacity in space science and technology and obtaining scientific results from space missions in a reasonably short time.

I personally am still very thankful for all the direct help I was able to obtain from NASA in carrying out space experiments with sounding rockets and satellites developed at the newly-established Max-Planck-Institute for Extraterrestrial Physics near Munich, which I was able to build up in the sixties. I am sure many scientists in Europe feel the same way as I do.

But one should also ask what were the objectives of the United States in offering this cooperation? A paper by John M. Logsdon identifies three types of objectives for NASA's international programmes:

(i) Scientific and technical objectives

- Increasing brainpower working on significant problems and expanding scientific horizons by making space an attractive field for research.
- Shaping the development of foreign space programmes to be compatible with the US effort 'by offering attractive opportunities to do it the US way'.
- Through such influence, limiting funds available in other countries for space activities competitive or less compatible with US interests.
- Obtaining unique or superior experiments from non-US investigators.
- Obtaining coordinated or simultaneous observations from multiple investigators.
- Increasingly, making available opportunities for US scientists to participate in space-science missions of other countries or regions.

(ii) Economic objectives

- By sharing leadership for exploring the heavens with other qualified space-faring nations, NASA stretches its own resources and is free to pursue projects which, in the absence of such sharing and cooperation, might not be initiated; NASA estimates getting over $2 billion in cost savings and contributions from its cooperative programmes over the past 25 years.
- Improving the balance of trade through creating new markets for US aerospace products.

(iii) Political objectives

- Creating a positive image of the United States.
- Encouraging European unity.
- Reinforcing the image of US openness, in contrast to the secrecy of the Soviet space programme; when NASA was organised ...the keystone of Government space policy was to give dramatic substance to the claim of openness — and, at the same time, to seek credibility for the nation's assertion that it entered space for peaceful, scientific purposes. This was done... most importantly, by inviting foreign scientists to participate extensively and substantively in space projects themselves.
- Using space technology as a tool of diplomacy to serve broader foreign-policy objectives.

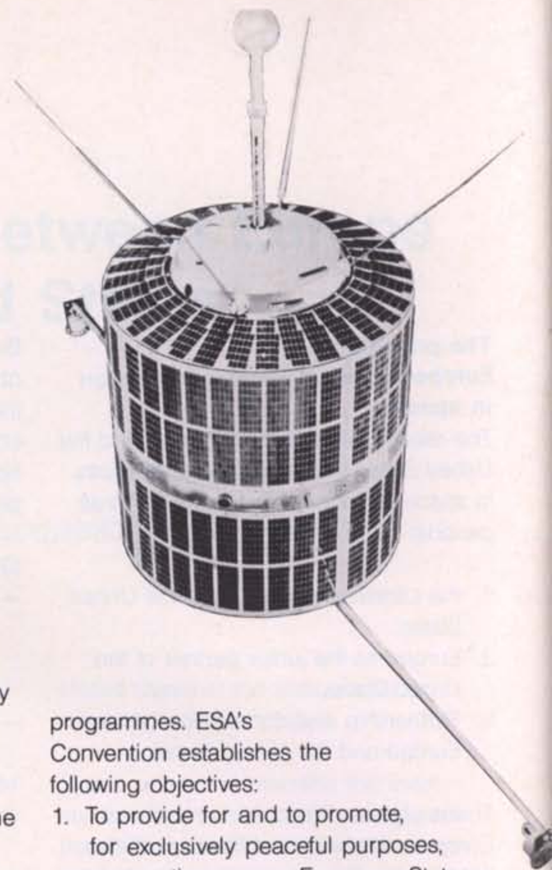
To fulfil these objectives, NASA had established guidelines with the following essential features:

- Cooperation is on a project-by-project basis, not on a programme or other open-ended arrangement.
- Each project must be of mutual interest and have clear scientific value.
- Technical agreement is necessary before political commitment.
- Each side bears full financial responsibility for its share of the project.
- Each side must have the technical and managerial capabilities to carry out its share of the project: NASA does not provide substantial technical assistance to its partners, and little or no US technology is transferred.
- Scientific results are made publicly available.

The United States as Europe's tutor

In Europe, several scientists had realised at the beginning of the sixties that national space projects alone would not be the right step to take Europe into space and that Europe could only achieve something meaningful if one could bring together all sources in order to work together. The example used was the very successful European cooperative endeavour in High-Energy Physics taking place through the establishment of CERN in Geneva. Finally, these scientists convinced their Governments to create a European Space Research Organisation

ESRO-IB



(ESRO) and the Government representatives held their first meeting on the premises of CERN on 1 December 1960. The European Space Research Organisation was eventually formally established in 1964 with ten Member States: Belgium, Denmark, France, Germany, Italy, the Netherlands, Spain, Sweden, Switzerland and the United Kingdom.

Even before ESRO officially started its work, contacts had been established with NASA, which offered its help in launching (with Scout rockets) ESRO's first two scientific satellites — ESRO-II (Iris) on 17 May 1968, and ESRO-IA (Aurorae) on 3 October 1968 — free of charge as cooperative projects. I was directly involved, as ESRO's first Scientific Director, in those negotiations with NASA.

However, in mentioning these two European satellites as cooperative projects with NASA, I should not forget NASA's cooperative projects with individual European countries and the numerous flight opportunities on US spacecraft offered to scientific groups in Europe. In this way we scientists in Europe were able to learn the state of the art in space experiments and many links were established between scientific groups in Europe and the United States that still exist today. By the end of 1969, the year in which the first Apollo craft (Apollo-11) landed on the Moon, nine European spacecraft had been launched by the United States on a cooperative basis.

This was the 'golden age' of the US space programmes. The momentum of cooperation has been carried through to the present day but, as one top-level participant has commented: 'when resources abound and opportunities are plentiful, a cooperative attitude abounds... When the resources and opportunities shrink, ...altruism takes a back seat and ... scientists take a more selfish view of cooperation'.

Europe as the junior partner of the United States

By the beginning of the seventies, not only had scientific groups gained the competence and confidence to develop space experiments, but also European industry had developed 17 satellites (12 national and 5 ESRO satellites), and gained the experience necessary to begin the development of applications satellites. Until then, all of ESRO's scientific satellites had been launched by US launch vehicles and paid for by ESRO, since they were not cooperative projects, with the exception of ESRO-I and ESRO-II. But, at the beginning of the seventies, Europe wanted to have a guarantee from the United States Government that all applications satellites — especially those for communications purposes — would also be launched by US launch vehicles on a reimbursable basis. Although the response from the United States sounded very positive, the conditions attached were seen in a more negative light on the European side. This finally triggered the decision in Europe to start development, with strong French investment, of the European launcher, 'Ariane', so that Europe would not only have its scientific satellites programme, but would also go ahead with the development of applications satellites for communications and meteorology.

ESRO was not equipped to carry out this much expanded programme as it had been set up as an organisation purely for scientific space research. The European Space Agency was therefore formed in 1975, retaining the existing ESRO establishments; namely the Headquarters in Paris, the Technical Centre (ESTEC) in Noordwijk (The Netherlands) and the Operations Centre (ESOC) in Darmstadt (Federal Republic of Germany) as essential elements. ESA now has 13 Member States: Austria, Belgium, Denmark, France, Germany, Ireland, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland and the United Kingdom, while Finland and Canada are cooperating with the Agency in certain programmes. ESA's Convention establishes the following objectives:

1. To provide for and to promote, for exclusively peaceful purposes, cooperation among European States in space research, space technology, and their space applications.
2. To elaborate and implement a European space programme.
3. To elaborate and implement an industrial policy.

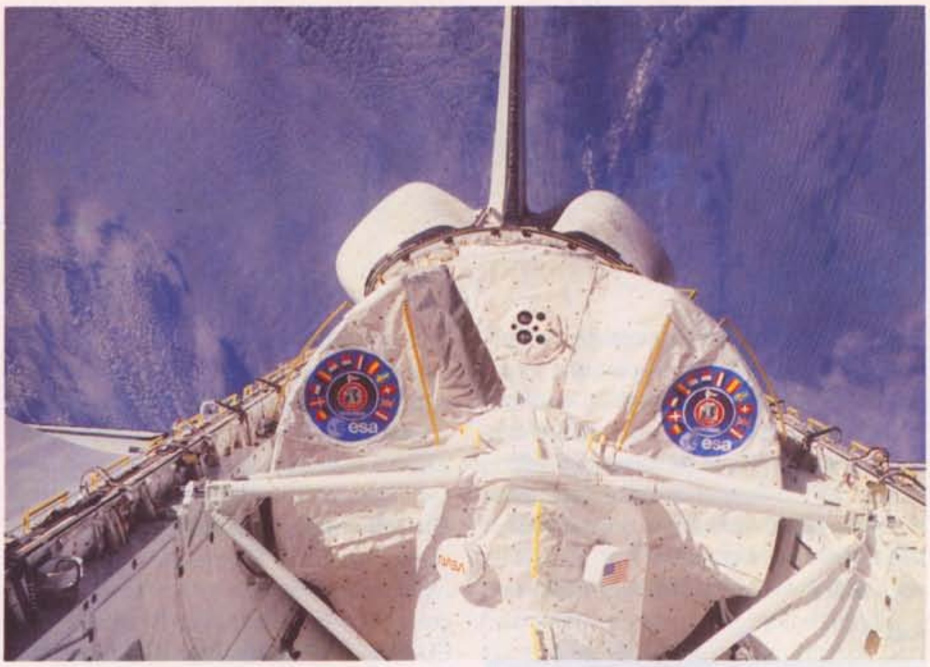
As Europe is composed of independent States, clear identification of the real European aims and tasks, as well as the harmonisation of national ideas and goals, is necesary. True collaboration will only be possible as far as consensus can be reached between the sovereign partners.

In order to facilitate collaboration within ESA, two kinds of ESA programmes have been made possible: the mandatory programme in which all Member States participate, according to their GNP, and a whole series of optional programmes financed by Member States based on their interest in each particular programme.

The mandatory programme includes the basic activities necessary for the general operation of the organisation and covers the costs of the research carried out at ESTEC in Noordwijk, and also the scientific spacecraft programme.

The optional programmes cover space applications in the widest sense.

Spacelab



Examples are those for communications satellites and for Earth observation, as well as those for research in the microgravity environment, and space-transportation systems such as Ariane, the manned space laboratory Spacelab, and hopefully Columbus, the Space-Station programme.

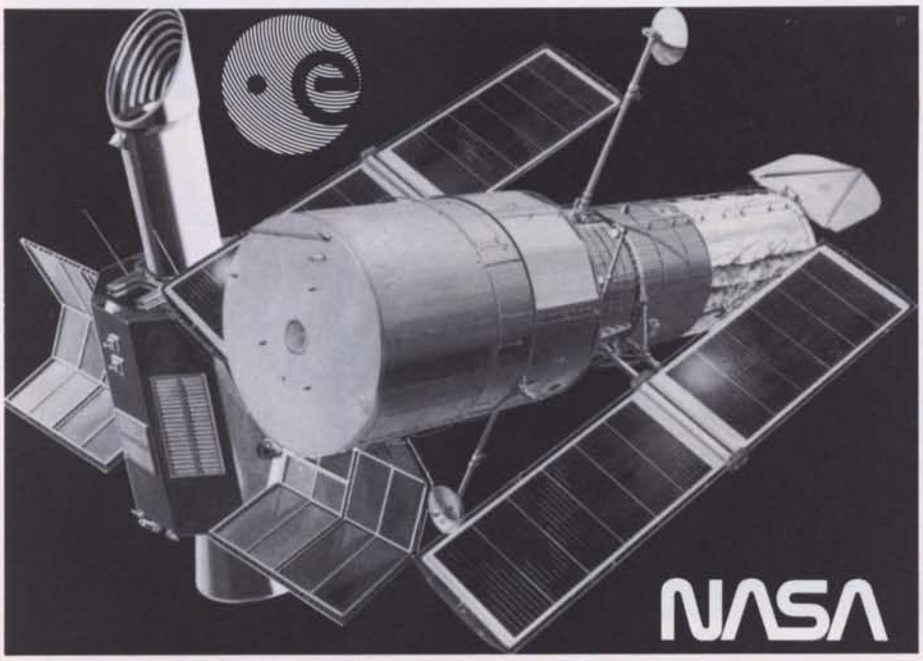
On its formation, ESA continued the cooperation with NASA already so well established by ESRO in space science. An outstanding example of this cooperation is the Space Telescope, to which Europe is contributing the Faint Object Camera (FOC), the solar array and ground operations support, representing some 15% of the total costs. Other examples are the International Ultraviolet Explorer (IUE) satellite and 'Ulysses', a mission that will explore the heliosphere at all solar latitudes, including the solar poles, for the first time.

In the area of applications satellites also, a certain degree of coordination has taken place between ESA and NASA or other US Agencies: with NOAA (National Oceanic and Atmospheric Administration) in meteorology, and through INMARSAT, for whom ESA has provided two satellites for the world maritime tele-communications network.

The largest ESA/NASA cooperative project to date has been Spacelab, for the United States' Shuttle. Spacelab was developed by ESA and then handed over to NASA after an initial joint NASA/ESA mission on which the first European Astronaut, Ulf Merbold, flew as a payload specialist. I will not discuss in detail the history of how the Agreement on Spacelab was concluded, except to say that it was later felt by some Europeans that the deal was not a fair one in that after completion Europe had to hand over ownership of the Spacelab hardware to the United States and now has to pay the full price for its use. In my opinion, this can only be understood in the light of the circumstances prevailing in 1973. In addition, we on the European side should take into account all the opportunities offered to us before Spacelab.

However, one fact is obvious, and that is that now that Europe has demonstrated its competence with Spacelab and with the success of Ariane, it will not again accept an Agreement on a cooperative project in which the terms would be similar to those applicable to the Spacelab Agreement. European States now feel very strongly that any future Agreement must be based on the principle of full partnership.

Space Telescope

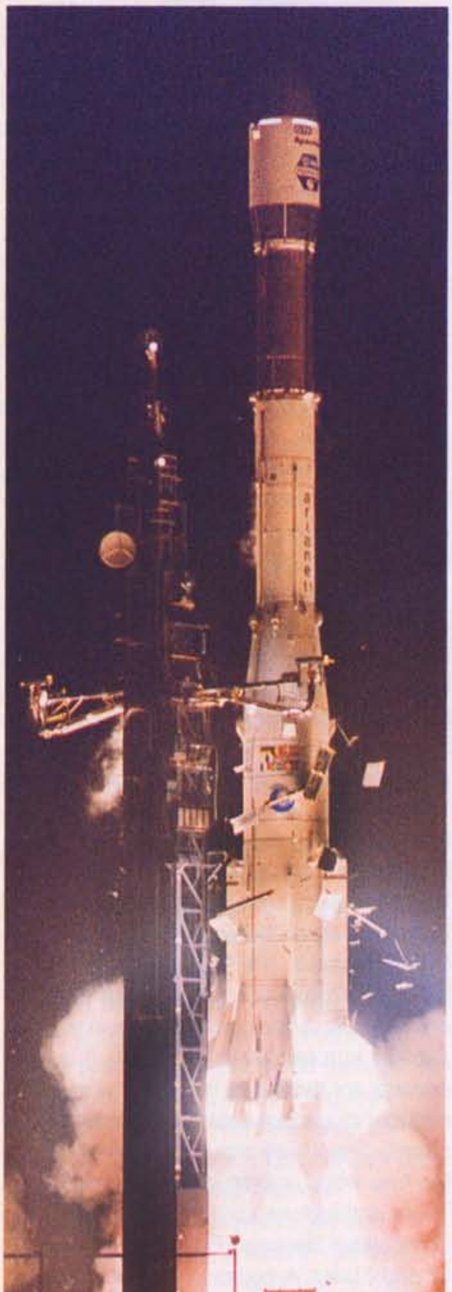


Partnership and competition between Europe and the United States

We are now in a phase of partnership and competition between Europe and the United States in the field of space activities. Competition should not rule out cooperation, if we compete with one another in a fair way. In industry, it is not unusual for two large firms that compete strongly in certain areas to cooperate in others. The whole economic system of the free world is based on competition. There is therefore nothing wrong with competition between Europe and the United States in certain areas of space activities.

The area of strongest competition at the moment is in the launcher domain. Ariane has already launched 21 satellites, and 42 more are booked for lauch in the coming years. This is no longer an ESA activity, as the Agency regards itself as a research and development organisation rather than an operator in the applications field. For this reason, the Ariane launch activities have been taken over by a commercial firm, 'Arianespace', which sells the Ariane vehicle and undertakes the launches from the site at Kourou in French Guiana.

Ariane

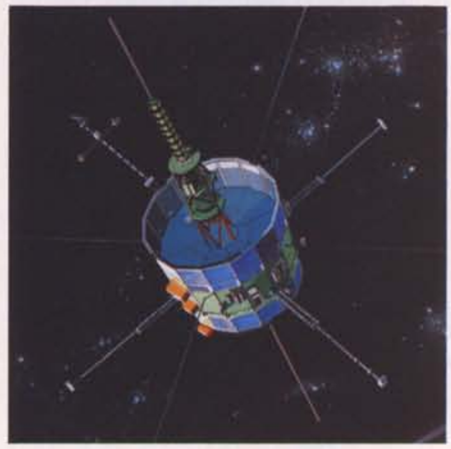


The other field of competition is that of communications. Here again, a European organisation has come into being, created by the European PTTs, called EUTELSAT. It operates the European communication satellites that have been developed so far by ESA.

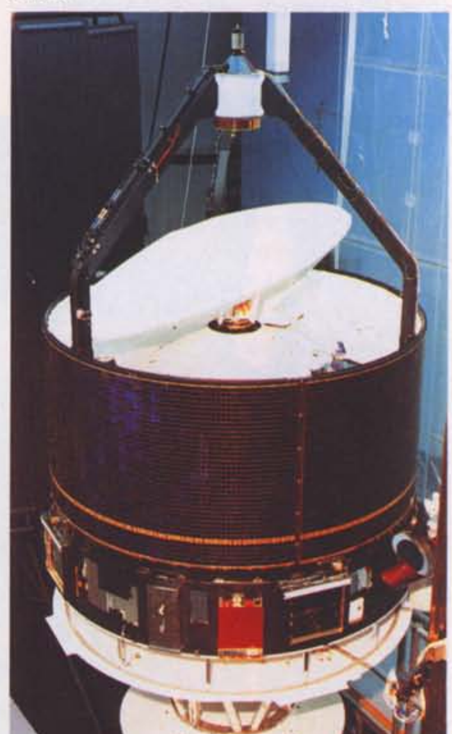
Whilst these competitive efforts have been taking place, there have still been strong ties of cooperation between Europe and the United States in space science and in Earth observation. An outstanding example is the coordination of the space missions to Halley's Comet. Here, not only Europe and the United States cooperated; indeed scientists all over the world worked together. The space agencies of Europe, Japan, the Soviet Union and the United States coordinated their space missions and worked together very closely through the Inter-Agency Consultative Group. The missions of two Soviet spacecraft Vega-I and Vega-II, the two Japanese Spacecraft Sakigake and Suisei and the European spacecraft Giotto, were coordinated in this forum.
Finally, NASA set a spacecraft on its way to Halley's Comet by redirecting its International Sun-Earth Explorer (ISEE-3), renamed the International Cometary Explorer (ICE), which had ten American and three European experiments onboard. The closest flybys of all of these spacecraft occurred in March 1986.

The most remarkable element in the cooperative effort for the Halley's Comet encounters was the so-called 'Pathfinder Concept', in which the Soviet Space Institute IKI, NASA's Deep-Space Network, and ESA's Operations Centre at Darmstadt, worked together to establish the exact position of Halley's Comet so that the Giotto spacecraft could flyby as close as possible. Optical ground observations alone were not sufficient for the accuracy needed. The two Soviet Spacecraft, Vega-I and Vega-II, were able to determine the relative position of Halley's Comet, but the Russian tracking stations were not able to give the positions of these spacecraft accurately enough. This was done by NASA's Deep-Space Network. ESA's Operations Centre received, by direct links from Moscow

ICE



Giotto



and from Pasadena, the information needed to correct Giotto's orbit slightly just 24 h before closest encounter. As a consequence, Giotto passed within 600 km of the comet's nucleus, which was photographed in close-up for the first time in history.

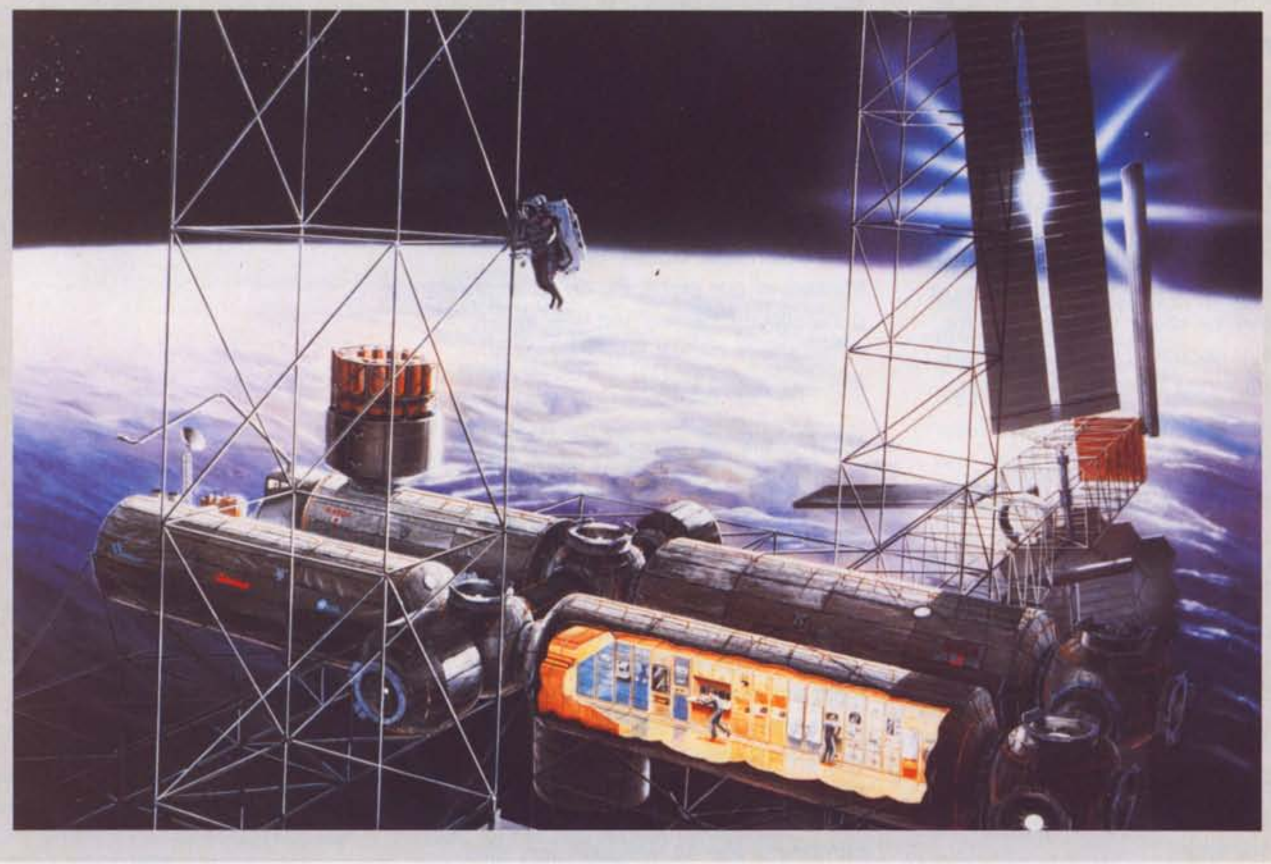
The Giotto mission was also remarkable in another respect: for the European/United States cooperation. From the outset, NASA had offered space for experiments on practically all of its missions to scientists all over the world. European scientists in particular availed themselves of those early opportunities to a large extent. In the sixties and seventies, those ESA missions that were not cooperative missions with NASA were, in principle, open only to scientists from ESA Member States, although exceptions were always possible. At the beginning of the eighties, however, ESA agreed to open its future missions also to US Principal Investigators. Giotto was therefore the first non-cooperative ESA mission open to US scientists, and nine of its ten experiments have US Co-Investigators (a total of 33 individuals).

By far the most difficult project for cooperation between the United States and Europe at present is the planned Space Station. In 1984 President Reagan invited Europe, Japan and Canada to participate in this great undertaking. The Member States of ESA, during a meeting of Ministers in January 1985 in Rome, accepted this invitation in principle. But they also stated very clearly that cooperation in the development and use of the Space Station should be based on real partnership.

The two Agencies, ESA and NASA, are working together very closely on the definition of the Space Station and of the possible European contribution to it. This phase is covered by an Agreement — a so-called 'Memorandum of Understanding' — between ESA and NASA. An Agreement still has to be established for the development and operational phase of the Space Station. For this we need not only an MOU between the two Agencies, but also an Agreement between the Governments of the Participating States of Europe and the United States.

We have been discussing these Agreements for almost two years now. The negotiations to establish the parnership in legal and managerial terms are neither simple nor easy. Since Christmas 1986 the negotiations have

Space Station



become even more complex, because the Department of Defense (DOD) intervened on the United States' side, in order to ensure that it could use the Space Station if necessary. ESA has Member States (e.g. Austria, Sweden and Switzerland) that are particularly sensitive to these questions, and the ESA Convention explicitly states that ESA can be involved only in projects for peaceful purposes. This certainly would not exclude specific research efforts by the DOD, but how can one find an Agreement that covers everything for the future?

I personally feel very strongly that it is very important both for Europe and the United States that we work together on the Space Station. However, both sides should be sufficiently flexible to understand the type of cooperation that would best serve the interests of the other.

European/United States cooperation in the future

In the past, cooperation between Europe and the United States has been extremely useful and beneficial to both sides. For the future also, a close working relationship between Europe and the United States holds much promise. This is true for many fields, but is most imperative for space activities and for science in general. From a European viewpoint, I can identify the following reasons:

— *Scientific and technical reasons*
- Bringing together brainpower
- Coordinating observations and research efforts
- Sharing resources for large and ambitious projects
- Exchanging space opportunities
- Stimulating the exchange of advanced technology.

— *Economic reasons*
- Strengthening Western industrial capacity

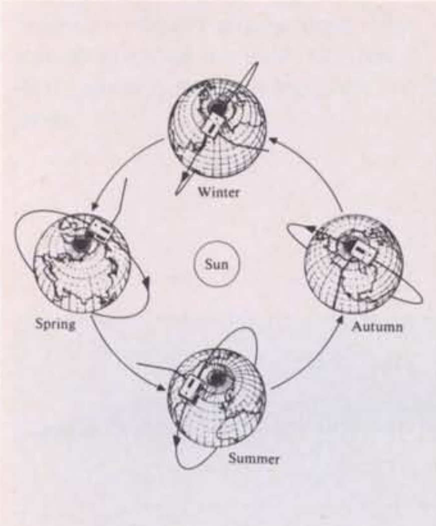
— *Political reasons*
- Strengthening trans-Atlantic partnership
- Increasing European unity.

That the Europe of today can be seen as an autonomous, real and reliable partner of the United States in various fields of science and technology is thanks to the immensely unselfish help given to it by the United States. The Europeans, who in some fields needed 40 years to recover from the disastrous second World War, are very much aware of this help and they thankfully acknowledge America's contribution to that recovery.

The great United States' personalities such as General George G. Marshall, who committed himself to that most important European recovery programme known as the 'Marshall Plan', will always be remembered. Another personality who has been of particular importance for the scientific re-development of Europe is Senator James William Fulbright. Thanks to the programme that he created and which carries his name, hundreds of thousands of young men and women from all over the world have been able to learn about other countries, and in particular about the United States. They have also been able to build up personal links which now cross most of the frontiers of our globe. By doing so, their generations have learned how to contribute to mutual understanding, assistance and peace.

Many of the key people of the post-war generation in Germany were Fulbright Fellows and learned about the United States with the help of this programme. They are now working in politics, in public life, in industry, in the news media and in the Universities and in other research institutes. However, some of them are reaching an age where they are leaving active duty. Many of the younger generation do not have such experiences of the United States. The imported US products that young Europeans see on television very often do not give a true picture of the United States. I feel it to be of great importance that many more of the new generation in Europe should continue in the Fulbright spirit and learn directly in the United States about the people and their country. At the same time, it is my hope that many more Americans will strengthen the ties in the other direction and look towards Europe.

First-hand knowledge of each other is so fundamental to the future cooperation between Europe and the United States. I experienced in a direct way how the development of science depends on the exchange of information and cooperation across national frontiers when I attended my first international conference as a young scientist — it was on cosmic rays. Personal contacts and friendships play a very important role. The Fulbright Fellowship was one of the great gifts in my life. Certainly we should do our utmost to ensure that young people in Europe and the United States are able to have similar experiences in order that cooperation between our two continents can continue to flourish in the future.



European Dissemination of Marine Observation Satellite (MOS-1) Data*

M. Egléme, Université Catholique de Louvain, Louvain-la-Neuve, Belgium

L. Fusco, ESA/Earthnet Programme Office, ESRIN, Frascati, Italy

In response to the increasing demand in Europe for remote-sensing products, ESA has entered into an agreement with Japan's National Space Development Agency (NASDA) for the operational acquisition, processing, and distribution of data from the Marine Observation Satellite (MOS-1). Although the satellite is dedicated to marine observation, MOS-1 data will have a wide range of potential applications in a variety of fields.

The mission objectives**

MOS-1, Japan's first Earth-observation spacecraft, is an experimental mission planned as the forerunner of a 13-year operational programme beginning in the 1990s. The overall programme is being developed and will be operated by NASDA. Five missions are planned, the first two of which, MOS-1 and MOS-2, have already been approved. The overall emphasis will be on ocean observation, but one of NASDA's objectives in developing MOS-1 is to establish basic technologies for global Earth observation.

The specifications for MOS-1's sensors were determined in 1976 based on the needs of Japanese users. The development programme started in March 1980, and the spacecraft design was finalised in June 1983. MOS-1 was manufactured by Nippon Electric.

Launched from the Tanegashima Space Centre on 19 February 1987, MOS-1 has a design lifetime of two years. It will be followed by MOS-1b in 1989. MOS-2 (1991—1993) will be a follow-on to MOS-1 using the same prototype model. The subsequent missions in the series will focus on marine observation at a time when the Japanese Earth resources satellite J-ERS-1 will be relaying more specific land information.

The MOS-1 satellite

The MOS-1 satellite, shown in Figure 1, is in a Sun-synchronous west-transiting orbit with a recurrence period of 17 days (Table 1). The latitude range extends approximately between 81°N and 81°S and any area in this band can be viewed under roughly the same solar illumination conditions (Fig. 2).

The MOS-1 and MOS-1b spacecraft will carry the same instruments (Table 2):

- two Multispectral Electronic Self-Scanning Radiometers (MESSRs) using CCD devices with a 50 m ground resolution in four bands in the visible and near-infrared regions of the spectrum (Fig. 3a).
- a Visible and Thermal Infrared Radiometer (VTIR) with a 900 m ground resolution in one band in the visible, 2700 m in two bands of the thermal infrared and one band in the water-vapour absorption range (6.0—7.0 μm) (Fig. 3b).
- a passive Microwave Scanning Radiometer (MSR) to measure very weak Earth radiation noise in the 31 and 24 GHz frequency bands with 23 and 32 km resolutions, respectively (Fig. 3c).

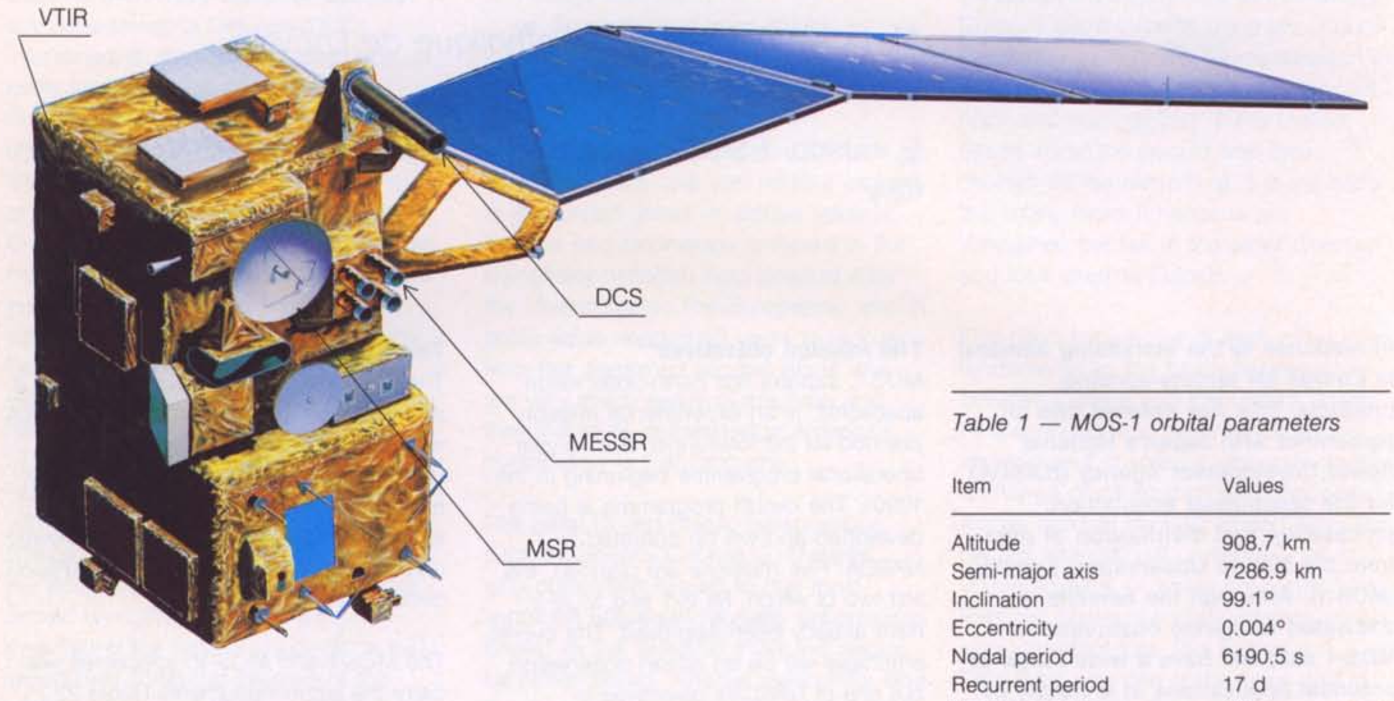
MOS-1 will also carry a Data Collection System (DCS) Transponder as a forerunner of a Tracking and Data Relay Satellite System (TDRSS) that will be used to collect and relay information in much the same way that the international Argos system developed by France and the United States already operates.

As there are no tape recorders aboard

* Based on the results of an 'Investigation of European User Needs in Accessing MOS-1 Payload', performed under ESRIN Contract in the second half of 1986.

**Tables and figures in this section are extracted from two NASDA publications: *Outline of the MOS-1 Earth Observation System*, NASDA Publ. HE-85414, 30 October 1985; and *MOS-1*, NASDA Information Brochure, March 1986.

Figure 1 — The MOS-1 spacecraft



MOS-1, ground stations are needed for data reception outside the tracking area of the Japanese Earth Observation Centre (EOC) receiving station.

ESA access to MOS-1

ESA's long-standing interest in accessing the MOS payload from European ground stations stems primarily from the need to stimulate further remote-sensing research and application activities by providing the user community with an alternative source of spaceborne data over Europe and northwest Africa. The imminent hiatus in Landsat data and the nonavailability of Landsat MSS data from Landsat-6 onwards have been two key factors in this scenario.

From the technological viewpoint, access to MOS-1 is valuable for validation of the ATSR/M instrument to be flown on the first European remote-sensing mission, ERS-1, as the VTIR and MSR elements of the MOS-1 payload have similar spectral and radiometric characteristics. Access to data from MOS's MESSR instrument will also allow further familiarisation with CCD devices and pushbroom scanning techniques.

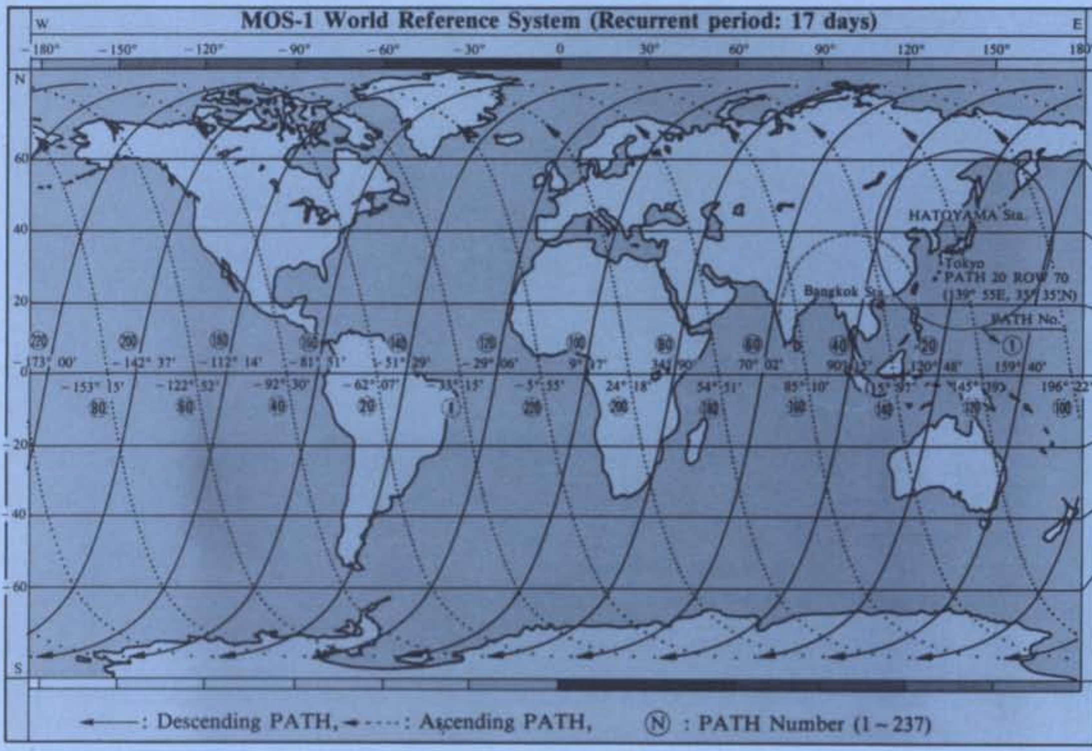
Table 1 — MOS-1 orbital parameters

Item	Values
Altitude	908.7 km
Semi-major axis	7286.9 km
Inclination	99.1°
Eccentricity	0.004°
Nodal period	6190.5 s
Recurrent period	17 d
Orbits per cycle	237
Orbital periods per day	14—1/17
Ground trace spacing at equator	167 km
Descending node time	10:00—11:00 AM

Table 2 — Characteristics of the MOS-1 payload

	MESSR		VTIR	MSR	
Objective	Sea-surface colour, vegetation, land use etc.	Suspended sediment	Stratospheric water vapour, Earth and sea-surface temperatures, etc.	Water-vapour content, liquid-water content, ice, snow, etc.	
Observation wavelength (μm)	0.51—0.59 0.61—0.69 0.73—0.80 0.80—1.1	0.5—0.7	6—7 10.5—11.5 11.5—12.5		
Instantaneous Field of View (km)	0.05	0.9	2.7	32	23
Swath width (km)	100 (each optic)		1500	317	
Scanning method	Electronic: pushbroom	Mechanical: rotating mirror		Mechanical: conical scan	
Scanning period	7.6 ms	1/7.3 s		3.2 s	
Data rate	9 Mbit/s		0.8 Mbit/s	2 kbit/s	

Figure 2 — MOS-1 ground track. The spacecraft circles the Earth 14 times in 24 h, returning to its starting point in 237 orbits



Descending ROW	Ascending ROW	Latitude Deg Min
492	491	80° 57'
496	487	80° 24'
10	477	76° 13'
20	467	70° 13'
30	457	63° 37'
40	447	56° 45'
50	437	49° 46'
60	427	42° 42'
70	419	35° 35'
80	407	28° 26'
90	397	21° 16'
100	387	14° 04'
110	377	6° 51'
119	368	0° 22'
120	367	– 0° 22'
129	358	– 6° 51'
139	348	–14° 04'
149	338	–21° 16'
159	328	–28° 26'
169	318	–35° 35'
179	308	–42° 42'
189	298	–49° 46'
199	288	–56° 45'
209	278	–63° 37'
219	268	–70° 13'
229	258	–76° 13'
239	248	–80° 24'
243	244	–80° 57'

ROW 1 ... 80° 80'N
ROW 119.5 } ... equator
ROW 367.5 }

The operational use of MOS-1 data will also pose several research challenges to the community of scientists and users, including:
- the development of models to relate MOS data to existing or previous Earth-observation and meteorological satellite data (MSS and TM on Landsat, HRV on SPOT, AVHRR on NOAA, and CZCS on Nimbus-7) and facilitate MOS interpretation;
- the development of algorithms for the integration of optical/microwave data and of high/low-resolution optical data;
- the development of atmospheric-correction models based on the VTIR water-vapour band.

All of the above led, in 1986, to a Memorandum of Understanding (MOU) between ESA and NASDA defining the terms and conditions of European access to the MOS-1 data.

The user response

European user interest in the Japanese MOS mission has evolved since 1984 from the need to broaden the space-derived data base and prepare for the breaks in Nimbus-7 CZCS and SMMR data and in Landsat data.

The major expectations from the operational use of MOS data in Europe are that:

- the availability of MOS-1 data from early 1988 onwards will fill the Landsat data gap and ensure continuity for ongoing research and application projects. The application projects expected to benefit most from MOS-1 input are those currently based on Nimbus-7 CZCS and Landsat MSS data;
- the use of simultaneously acquired VTIR data will also permit monitoring applications over large areas, especially in western Africa and western Mediterranean areas for desertification studies and oceanographic applications, respectively;
- the VTIR will provide an additional source of information in the water-vapour absorption band which will complement data from the AVHRR and Meteosat instruments;
- the use of MOS data will satisfy those applications that require both low and high ground-resolution data simultaneously;
- the complete European coverage and the large amount of data that can be collected from a single pass are valuable attributes for monitoring applications.

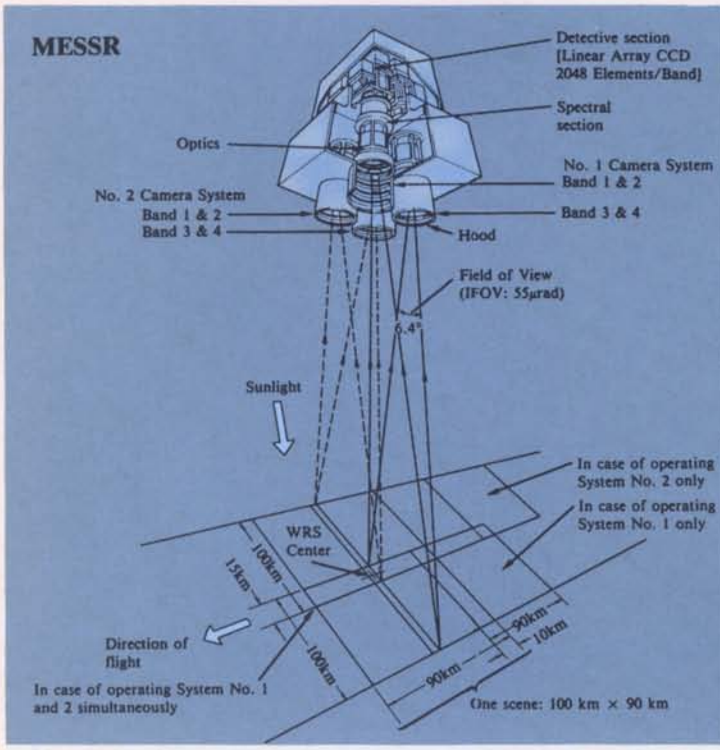
The relatively low cost of data from this experimental mission in the context of distribution via Earthnet is unquestionably a considerable attraction for many users.

In the recent poll of the scientific remote-sensing community to assess interest in the MOS-1 payload, 85% registered their intention to take part in a European MOS-1 Data Utilisation Programme

Figure 3a — MESSR instrument configuration and ground track. The two instruments are installed at a 5.46° cant angle

Figure 3b — VTIR instrument configuration and ground track

Figure 3c — MSR instrument configuration and ground track



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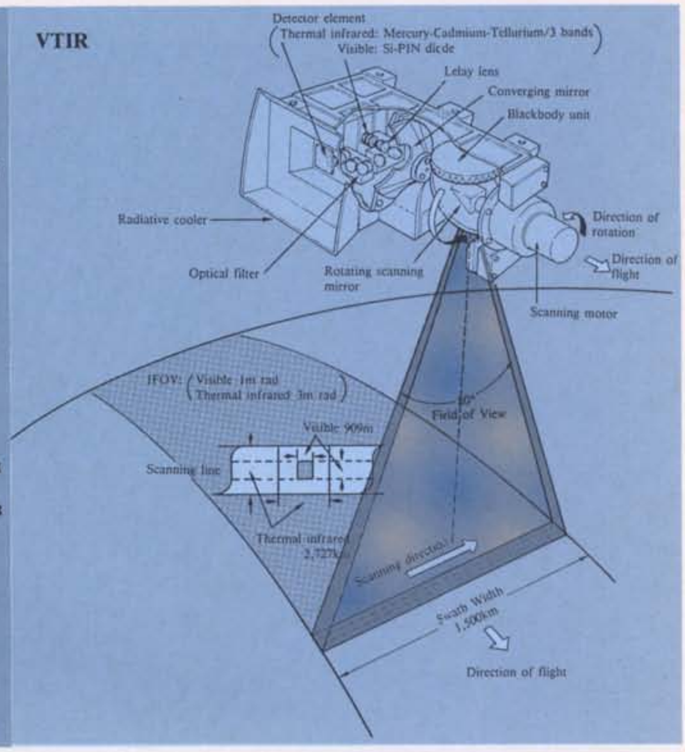

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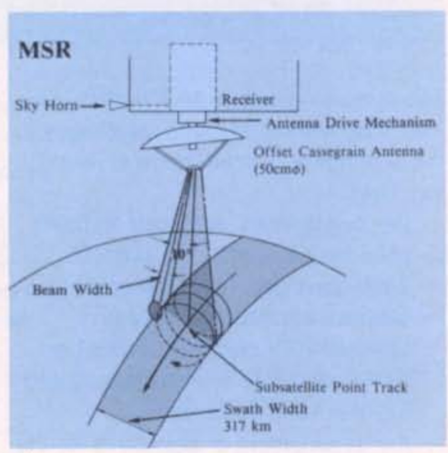


c)

(EMDUP) and submitted preliminary investigation topics in various fields of application, along with data requirements.

Potential applications and user priorities

Groups of potential applications that will exploit MOS-1 characteristics most effectively have been identified in the course of our investigations by matching expected MOS performances in the spatial, spectral and temporal domains (Table 3) with the user requirements for specific applications.

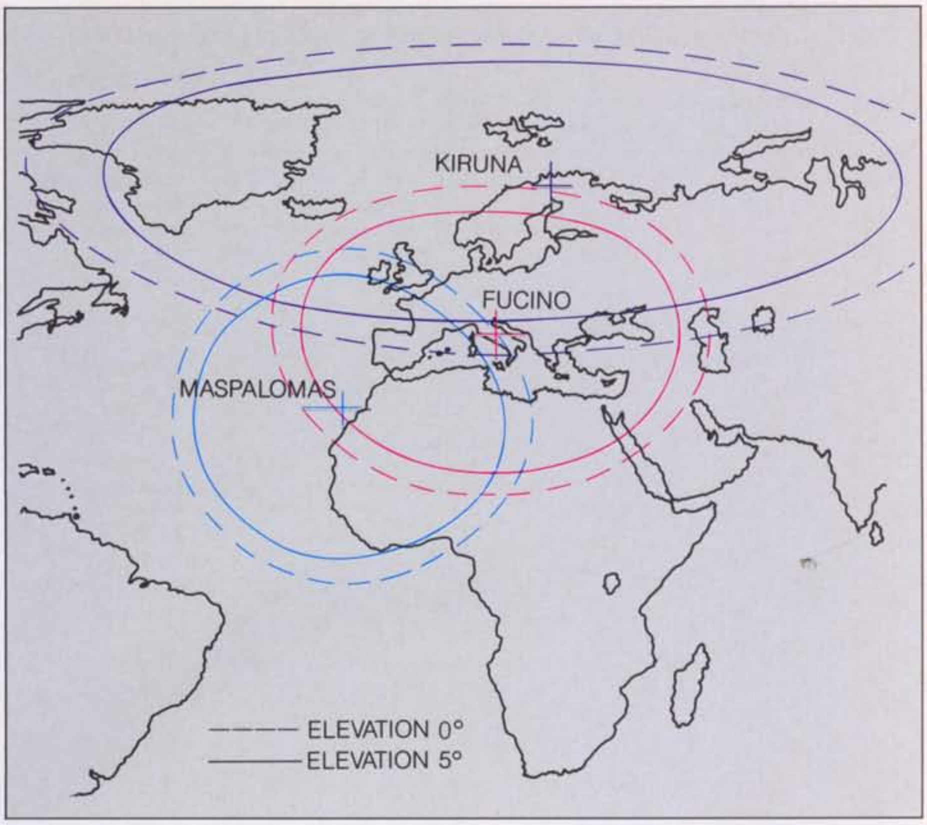
The market study underlined the strong need for data for continuing applications in the fields of geology, cartography, environmental monitoring, land use studies, and oceanography. The fields of meso-climatology and oceanography of polar seas are also expected to benefit greatly from MOS-1 data inputs. There was a clear requirement from the user community for data for monitoring applications and for temporal continuity in observations. There was also interest in the integration of simultaneously acquired data from the MESSR and the VTIR for agronomical- and agrometeorological-related applications in agriculture and forestry (evaluation of evapotranspiration). Coastal-zone dynamics, sea-surface-temperature identification, and marine-pollution studies are expected to benefit from the co-registered VTIR/MESSR data sets. In response to the European user survey, a total of 72 themes were proposed for operational applications.

As far as oceanographic applications are concerned, MOS high-gain-mode data is expected to permit semi-quantitative monitoring of coastal processes in the visible and infrared regions of the spectrum (more useful for nearshore dynamics than for water constituents). Potential applications in coastal zones include studies on: large-scale eddy structures alongshore, sediment plumes, sediment transport patterns, circulation-pattern mapping, discharge of polluted waters into bays and lagoons, and wetland resources inventory. These applications would typically use data from the MESSR or the VTIR, or a combination of the two. Open-ocean applications that would use VTIR and MSR data include: sea-surface temperature, sea-ice observation and measurement, large-flow-pattern detection, and ocean currents.

Table 3 — Expected MOS-1 sensor performances for land, oceanic and atmospheric applications

Sensor	Band	Observation wavelength or frequency	Resolution	Sensitivity	Application fields: Land	Ocean	Atmosphere
MESSR	1	0.51—0.59 μm	50 m	Peak of reflected light from vegetatation; high transparency of water bodies; highly affected by atmosospheric effects	— Vegetation vitality — Snow-pack identification — Volcanic ash identification — Land-use classification	— Coastal zones and lake-water quality — Shallow-water bottom topography — Red-tides	
	2	0.61—0.69 μm	50 m	Vegetation differentiation (chlorophyll absorption)	— Land use classification — Geological mapping — Vegetation types — Distinction between green/bare grounds — Snowpack mapping — Forestry management — Agriculture management — Volcanic ashes	— Eddy currents — Coastal zones and lakes — Red-tides	
	3	0.72—0.80 μm	50 m	High transparency through haze	— Land/water separation — Wetland mapping — Agriculture management — Forestry management — Geological mapping	— Shoreline delineation	
	4	0.80—1.1 μm	50 m	Near-infrared land/water separation	— Flood-plain delineation — Agriculture management — Forestry management — Lake shore management — Fire damage assessment — Topography — Water systems (hydrography)	— Offshore ice — Shoreline delineation	
VTIR	1	0.5—0.7 μm	900 m	Visible (blue and green)	— Snow-pack/ice mapping	— Suspended sediments	— Daytime cloud mapping
	2	6.0—7.0 μm	2700 m	Water vapour band; high absorption (near 100%)			— Statospheric water vapour — Thin cirrus cloud detector
	3	10.5—11.5 μm	2700 m	Atmos. window thermal IR; atmos. water vapour	— Snow/ice mapping — Thermal radiation budget (surf. temp.) — Large heat islands	— Ocean currents	— Day and night cloud mapping
	4	11.5—12.5 μm	2700 m	Same as above	Same as above	— Sea-surface temp. — Ocean currents	Same as above
MSR	1	23.8 GHz	32 km	Water-vapour and droplets; snow; ocean winds; water-vapour absorption at 22.235 GHz	Snow-pack measurement		— Amount of water vapour — Front observation — Rain region observation — Snowfall measurement — Precipitation mapping
	2	31.4 GHz	23 km	Ocean ice; water droplets; oil film; snow	Same as above	— Sea-ice concentration mapping — Oil-contaminant measurement	— Cloud moisture measurement

Figure 4 — MOS-1 data coverage from the European stations at Fucino (Italy), Kiruna (Sweden) and Maspalomas (Canary Islands)



For vegetation and agricultural applications, MOS is not expected to play a key role in most European countries, even in the case of Landsat failure, due to the poor spatial resolution available (and temporal resolution for applications in agriculture and forestry). Proposed applications include: plant stress and biomass, contributions to agricultural land use pattern studies and forestry management, and large-scale vegetation indices. Most applications in these fields involve vegetation-degradation monitoring in semi-arid areas.

There are higher expectations in the field of geology and mineral resources, despite the lack of a stereo capability and relatively poor spatial resolution, for such applications as: studies of hydrothermal fluid patterns and related mineralisation processes, structural mapping, tectonics, and localisation of ore deposits.

Potential applications in hydrological and soil studies will primarily be at a regional level for water management, vegetation and soil patterns on slopes of large hydrological basins. MOS-1 is not expected to make a significant contribution to urban studies in Europe.

The MSR data will be used to measure liquid water and water-vapour content in the atmosphere and at the air/sea interface, and meso-scale rain features in precipitation mapping. Studies of sea and inland ice will also take advantage of MSR data availability.

ESA's plans for product management
The acquisition, pre-processing, and distribution of MOS-1 products in Europe will be managed by the ESA/Earthnet Programme Office (EPO). The ground receiving stations Maspalomas, Fucino, and Kiruna have been selected to ensure complete data coverage for Europe and northwestern Africa (Fig. 4); the Tromsφ station will also track MSR data. All acquisition stations are equipped with pre-processing and archiving facilities.

Table 4 — ESA/Earthnet MOS-1 product types

	Data recording density 1600 bpi	6250 bpi	Number of unit products
MESSR*	Yes	Yes	1
MESSR + VTIR	Yes	Yes	2
VTIR	Yes	Yes	1
MSR	Yes	Yes	1
VTIR + MSR	Yes	Yes	2
MESSR + MSR	Yes	Yes	2
ALL (MESSR + VTIR + MSR)	No	Yes	3

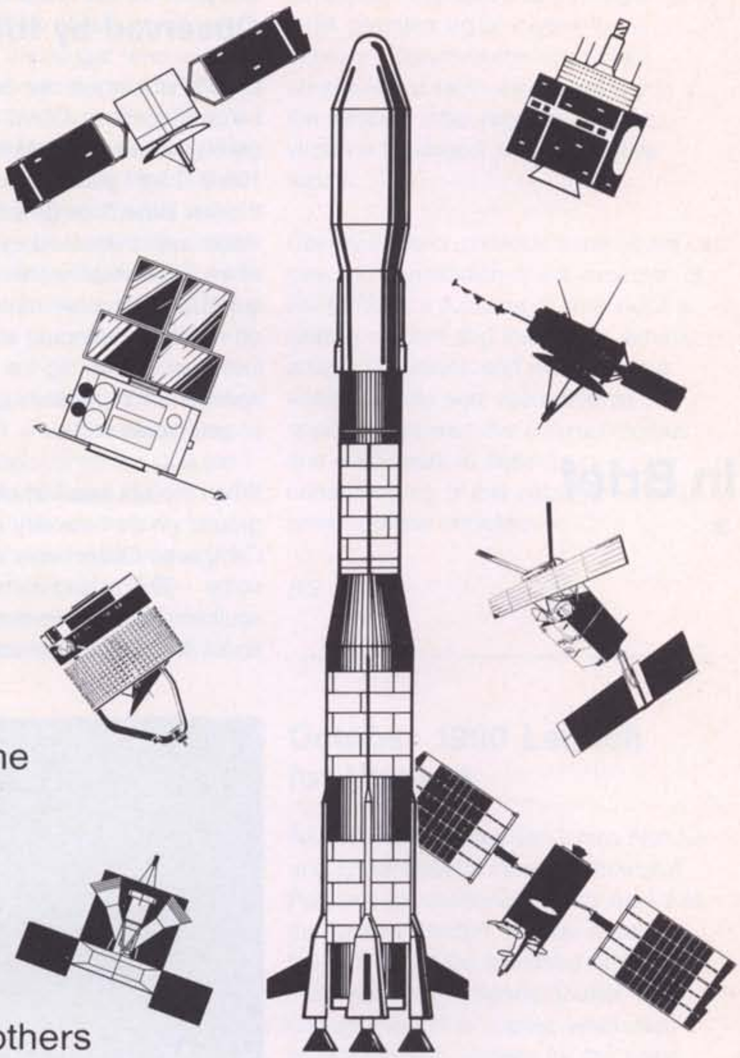
* MESSR full scene. If VTIR is available at the same time, 110 lines of data (approximately 15 s acquisition time) will be added.

MESSR data will be processed at two levels: raw and system-corrected (similar to Earthnet products for Landsat MSS and TM). The raw VTIR image products will be complemented with radiometric correction parameters and geometric location. There will be no processing for MSR data.

ESA/Earthnet will offer basic MESSR and VTIR products on 1600 or 6250 bit/inch computer-compatible tapes (CCTs). Products related to different MOS-1 instrument data acquired at the same time will also be available on CCTs. A total of seven different products will be made available (Table 4). There are no plans to provide photographic products in the short term.

MOS-1 products are to be made available first to the participants of the European MOS-1 Data Utilisation Programme (EMDUP). The main objective of EMDUP is to demonstrate the usefulness of the data for operational applications in various fields and to carry out basic scientific and technological validation.

ESA's prime objective in disseminating MOS products remains that of providing the user community with a continuous supply of spaceborne data and stimulating operational applications in remote sensing. Subject to a successful outcome to this first Japanese mission, it is envisaged to extend the MOU for MOS-1 to the subsequent missions in the series.



In Brief

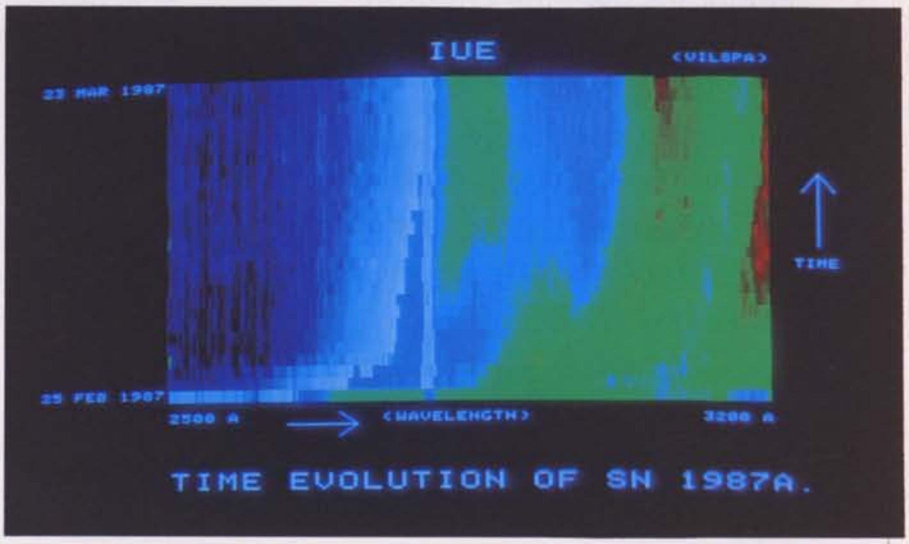
Supernova 1987A Observed by IUE

On 23 February a star 'exploded' in the Large Magellanic Cloud (LMC), the galaxy closest to the Milky Way, some 160 000 light years from Earth. This is the first supernova (SN) that has been visible with the naked eye since 1604, when Supernova Kepler was observed in our Galaxy. The full impact of this event on modern astronomy with its range of instruments covering the electromagnetic spectrum from radio to gamma rays is, as yet, incalculable.

When the SN was first observed from the ground on 24 February at the Las Campanas Observatory (its declination of some −69° making it visible only at southern latitudes) its magnitude was about 4.5, roughly the same as a star of the Pleiades cluster (the 'Seven Sisters'). This makes it, for the time-being at least, the brightest object in the LMC.

All southern ground-based telescopes (including amateur) were brought to bear on the SN, while the planned observing programme of the International Ultraviolet Explorer (IUE), from both ESA's Villafranca tracking station and NASA's Goddard Space Flight Center, was quickly altered to include observations of the SN.

Examination of the records of neutrino telescopes deep underground in the Alps, in Japan and in the USA recorded time-separated, short bursts of neutrinos early on 23 February. These bursts are linked to the initial collapse of the progenitor star and mark the start of the supernova event.



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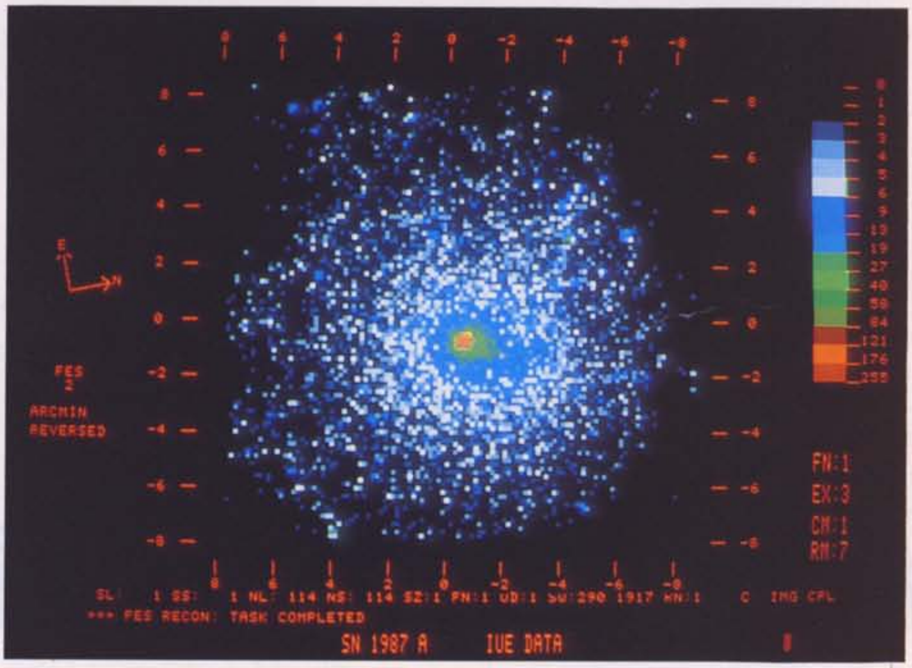

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Early optical observations and comparison with previous records suggested a faint, very hot, B2 I supergiant star, designated Sanduleak −69202, as the progenitor, though optical plates showed this star to have two companions within a few seconds of arc.

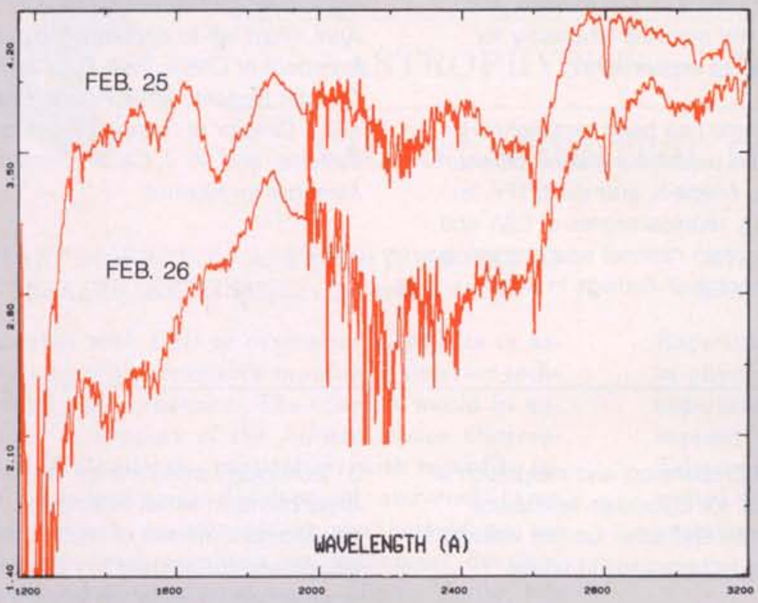
The visible light curve of the SN as monitored by the IUE fine error sensor up to the end of March is shown in Figure 1 with an image shown in Figure 2. By the end of April the increase in intensity appeared to have levelled off, and the SN had reached about magnitude 3.

The SN was very bright in the UV to begin with but faded rapidly at the shortest wavelengths so that by early March it was hardly detectable. The rapid evolution in the UV spectrum between February 25 and 26 is clearly shown in Figure 3 and over the longer term in Figure 4. However from the middle of April onwards the UV flux was found to be increasing again, due probably to the decreasing opacity of the SN which was expanding initially at some 25 000 km/s, as determined from the width of spectral line features. (Seen from Earth, this corresponds to an increase in angular size of 0.25 arc sec per year.)

Very careful and painstaking observations with IUE of the SN and the nearby stars in the ultraviolet have confirmed that the progenitor was indeed Sanduleak −69202. With the limited sensitivity of currently orbiting instrumentation the SN has not yet been detected at X-ray (Ginga and Astron satellites) or gamma-ray (Solar Max) wavelengths. An Exosat telescope observation of the region in 1984 detected no precursor X-ray emission. Observations have been conducted at radio wavelengths and in the infrared, most recently from an airborne telescope, all with positive results.

Observations of previous supernovae can give some indication of the evolution of SN1987A as a function of time but it is already evident that this one is exhibiting unique properties and will provide a wealth of data and observational opportunities over the coming months and even years to better our understanding of this cataclysmic end-point of stellar evolution.

B.G. Taylor



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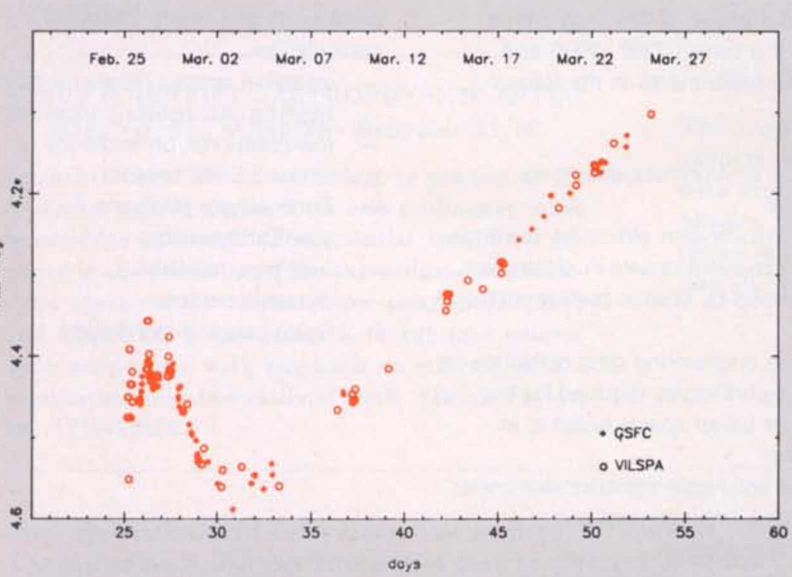

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October 1990 Launch for Ulysses

NASA's Administrator Dr James Fletcher and ESA's Director General Professor Reimar Lüst announced on 3 April that the joint NASA/ESA Ulysses mission to the Sun would be launched in October 1990 aboard the Space Shuttle. The Galileo mission to Jupiter, which was competing with Ulysses for the same launch window, will therefore be launched by the Shuttle in the earlier slot of October/November 1989.

This launch sequence decision was based principally on a desire to optimise the data return from the two missions. Although launched one year later than Galileo, the Ulysses spacecraft will begin to return prime data in 1994, one year earlier than the Galileo spacecraft, which has a longer journey time.

Due to the limited launch window for Ulysses, NASA has guaranteed ESA that the mission will receive top priority for an October 1990 launch.

Increased Safety Measures for Hermes

Following a reappraisal of Hermes safety requirements and a detailed analysis of the initial Hermes configuration, a new reference baseline for Hermes and Ariane-5 is being considered.

As a design goal, the total mass of Hermes has been assumed to be 21 t, in a low circular Earth orbit of 500 km with an inclination of 28.5°. This mass includes a payload of 3 t plus a fuel allowance of 1.5 t. This new baseline would require a corresponding adaptation of an Ariane-5 configuration from two solid boosters of 190 t and a liquid-core stage of 140 t to an updated version with two solid boosters of 230 t and a liquid-core stage with 155 t of propellant.

According to this revised concept, the Hermes spaceplane would be designed with an ejectable crew cabin as a more advanced safety system. Hermes would have a crew of three, a pressurised cargo bay, and a fuselage adapted for these changes.

Hermes has been foreseen to service the European part of the future manned Space Station, in particular the Man-Tended Free Flyer (MTFF). The MTFF, an element of the European Columbus in-orbit infrastructure programme, is a periodically manned laboratory for microgravity experiments.

A task force has been established to review the overall coherence between Hermes, Ariane-5, and the MTFF. Its members, representatives of ESA and Member-State national space agencies, will present their findings in May.

Signing of the Preparatory Programme agreement for Hermes, in Paris on 16 April. From left to right: Mr F. d'Allest, President of CNES; Prof. R. Lüst, ESA's Director General; Mr J. Feustel-Büechl, ESA's Director of Space Transportation Systems; and Mr J. Capart, Project Manager for Hermes

In-orbit Technology Demonstration Programme Approved

On 15 January the potential participants approved the start of the In-Orbit Technology Demonstration Programme (TDP), intended to provide in-orbit verification of new European space technologies that cannot be adequately tested on the ground.

Flight opportunities on a wide range of carriers, including the NASA and ESA Space Transportation Systems and future satellites, are foreseen.

The programme is intended both as a service for the European space technology community, in industry and research institutes, and to ensure the timely availability of the necessary technologies for future European space programmes. It will include assistance with the preparation and integration of payloads, for European aerospace companies and other bodies wishing to test their technologies in space.

The initial phase of the programme covers the period 1987–1990 and includes experiments in the following areas:

1. Space environment effects, in particular
   - atomic-oxygen effects on materials
   - single-event upsets in electronics caused by cosmic-particle radiation.

2. Space engineering data collection on critical technologies required for the design of future space systems, in particular:
   - the solid-state microaccelerometer
   - plume impingement and contamination
   - in-space aluminium coating.

3. Technology performance data; experiments in which technology development models of future spacecraft equipment are operated in the real space environment, to verify performance predictions and design margins, in particular for:
   - inflatable space-rigidised antennas
   - modular star-sensor performance
   - low-Earth-orbit performance of infrared Earth sensors
   - Earth sensor platforms
   - yaw Earth sensors
   - heat-pipe radiators
   - dynamic coolers
   - liquid-gauging technology.

12th Meeting between ESA and Japan

The twelfth meeting between ESA and Japan to discuss current space activities and future programmes took place from 13–16 April in Tokyo.

In the area of space science, Japan offered European scientists the opportunity of collaborative investigations aboard their X-ray astronomy satellite Ginga. As regards remote-sensing, mutual interest was expressed in the exchange of data from the Japanese J-ERS-1 and the European ERS-1 satellites. Information was also exchanged about the Polar Platform and the LASSO experiment on board the European Meteosat P2 satellite.

Both sides expressed satisfaction at the ongoing cooperation on the reception of data from Japan's Marine Observation Satellite (MOS-1) through ESA's Earthnet programme (see article on page 105). Telemetry, tracking and control support has already been provided by ESA for the MOS-1 launch, and is planned for MOS-1b and J-ERS-1.

ESA and Japan also presented their respective programmes on telecommunications and broadcasting, including data-relay services.

Following the Japanese proposal to strengthen cooperation in the area of space station utilisation, a joint working group is planned. As regards space transportation systems (STS), ESA presented its Ariane and Hermes programmes and future plans, while Japan presented its its H II and Space Plane studies. It was agreed to continue to exchange views and information on STS, and both sides were in favour of setting up an experts' meeting in Europe during the summer.

More generally, both ESA and Japan expressed their intention to promote the exchange of scientists and engineers.

The thirteenth meeting will be held in Paris in the spring of 1988.

ASTROPHYSICS — EUROPEAN SPACE AGENCY

VACANT SCIENTIFIC POSITIONS

STAFF SCIENTIST - ASTROPHYSICS, ESTEC
ESA/VN/ESTEC(85)52 - Reference 58/85

Scientist with PhD or equivalent in physics or astronomy with experience in infrared detector technology and cryogenics. The scientist would be engaged in support of the *Infrared Space Observatory (ISO)* mission, particularly with regard to focal plane instrument development, and would carry out research in infrared/sub-mm heterodyne astronomy, with emphasis on instrument development and observational work. (Brian Taylor, tel: 1719-83556)

STAFF SCIENTIST - ASTROPHYSICS, ESTEC
ESA/VN/ESTEC(86)25 - Reference 51/86

Scientist with PhD or equivalent in physics or astronomy with experience in sub-millimeter wave heterodyne systems. The scientist would be engaged in the definition of the sub-millimetre heterodyne spectroscopy 'cornerstone' mission (*FIRST*) and would carry out research in sub-mm heterodyne astronomy, with emphasis on instrument development and observational work. (Brian Taylor, tel: 1719-83556)

STAFF SCIENTISTS - STScI, Baltimore
ESA/VN/ESTEC(86)94 - Reference 115/86

Experienced astronomers with PhD or equivalent in physics or astronomy with substantial research experience. The scientists will be engaged in support of the in-orbit calibration of the Space Telescope Scientific instruments and would be expected to carry out an active scientific research programme. (Brian Taylor, tel: 1719-83556)

STAFF SCIENTIFIC SYSTEMS ANALYST
STScI, Baltimore
ESA/VN/ESTEC(87)71 - Reference 103/87

The scientific systems analyst will be engaged in support of Space Telescope scientific operations, data procesing and analysis. An M.Sc. or Ph.D in physics, astronomy or computer science with experience in image processing, treatment of large data sets etc. required. (Brian Taylor, tel: 1719-83556)

Send applications and curriculum vitae to Head of Personnel, ESTEC, Keplerlaan 1, 2201 AZ Noordwijk, The Netherlands. Further information may be obtained by contacting those persons indicated.

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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

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MODAL-SURVEY TESTING OF THE OLYMPUS SPACECRAFT
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A BI-DIRECTIONAL HIGH-POWER CELL USING LARGE-SIGNAL FEEDBACK CONTROL WITH MAXIMUM CURRENT CONDUCTION CONTROL FOR SPACE APPLICATIONS
CAPEL A ET AL

The following papers have been published in ESA Journal Vol. 11, no. 1:

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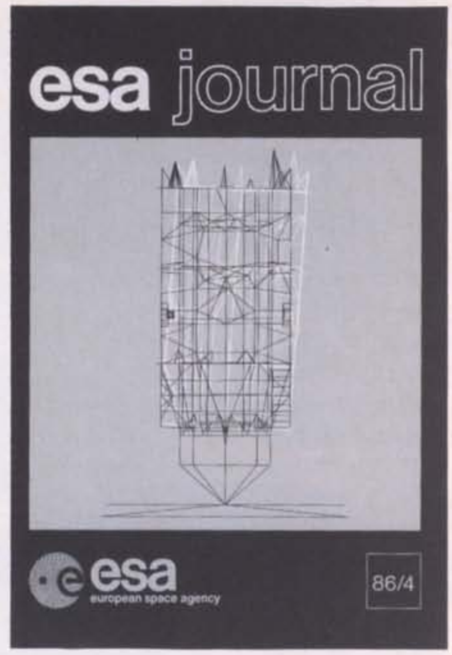

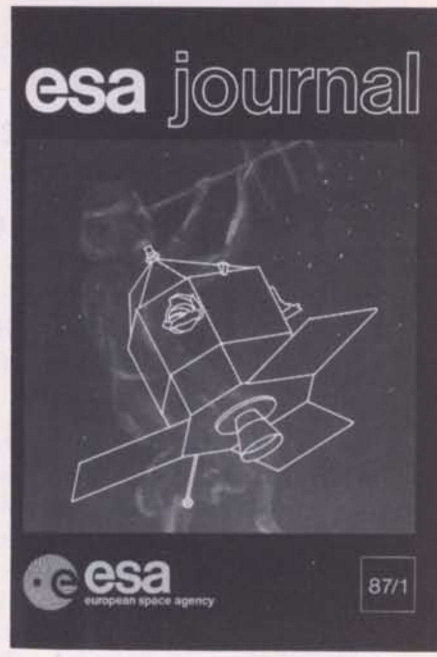

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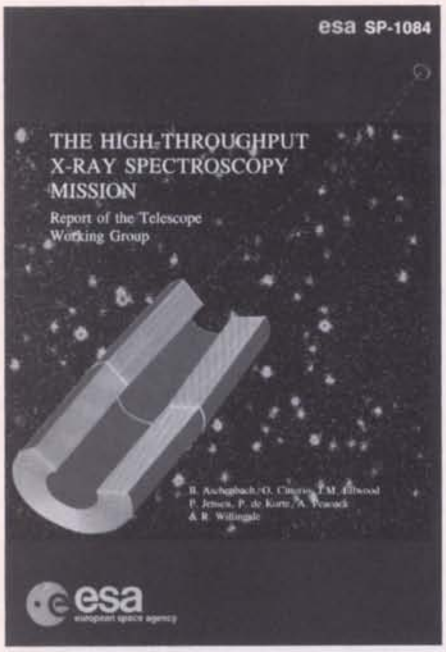

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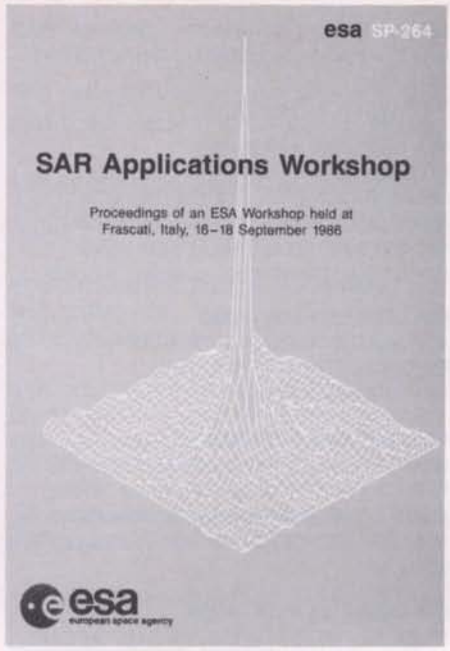

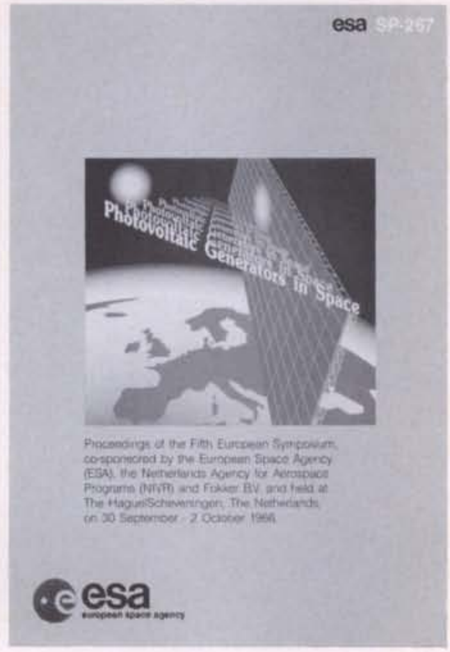

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