european space agency

agence spatiale européenn

esa bulletin

number 62

may 1990

european space agency

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

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

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

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

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

The ESA HEADQUARTERS are in Paris.

The major establishments of ESA are:

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

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

ESRIN, Frascati, Italy.

Chairman of the Council: Mr H. Grage.

Director General: Prof. R. Lüst.

agence spatiale européenne

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

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

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

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

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

Le SIEGE de l'ESA est à Paris.

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

ESRIN, Frascati, Italie

Président du Conseil: M H. Grage.

Directeur général: Prof. R. Lüst.

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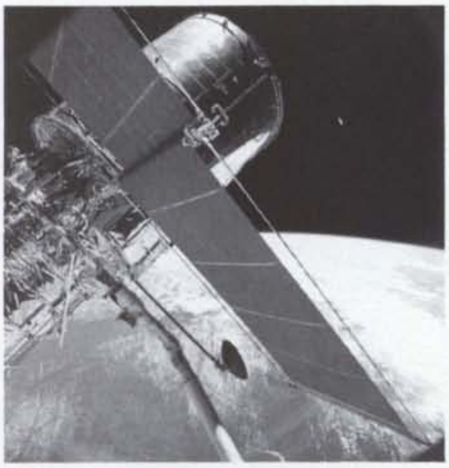

Cover: Hubble Space Telescope suspended in space from Space Shuttle Discovery's remote manipulator system, with one of the two ESA-provided roll-out solar arrays deployed in the foreground (see page 94)
(photo: courtesy of NASA)

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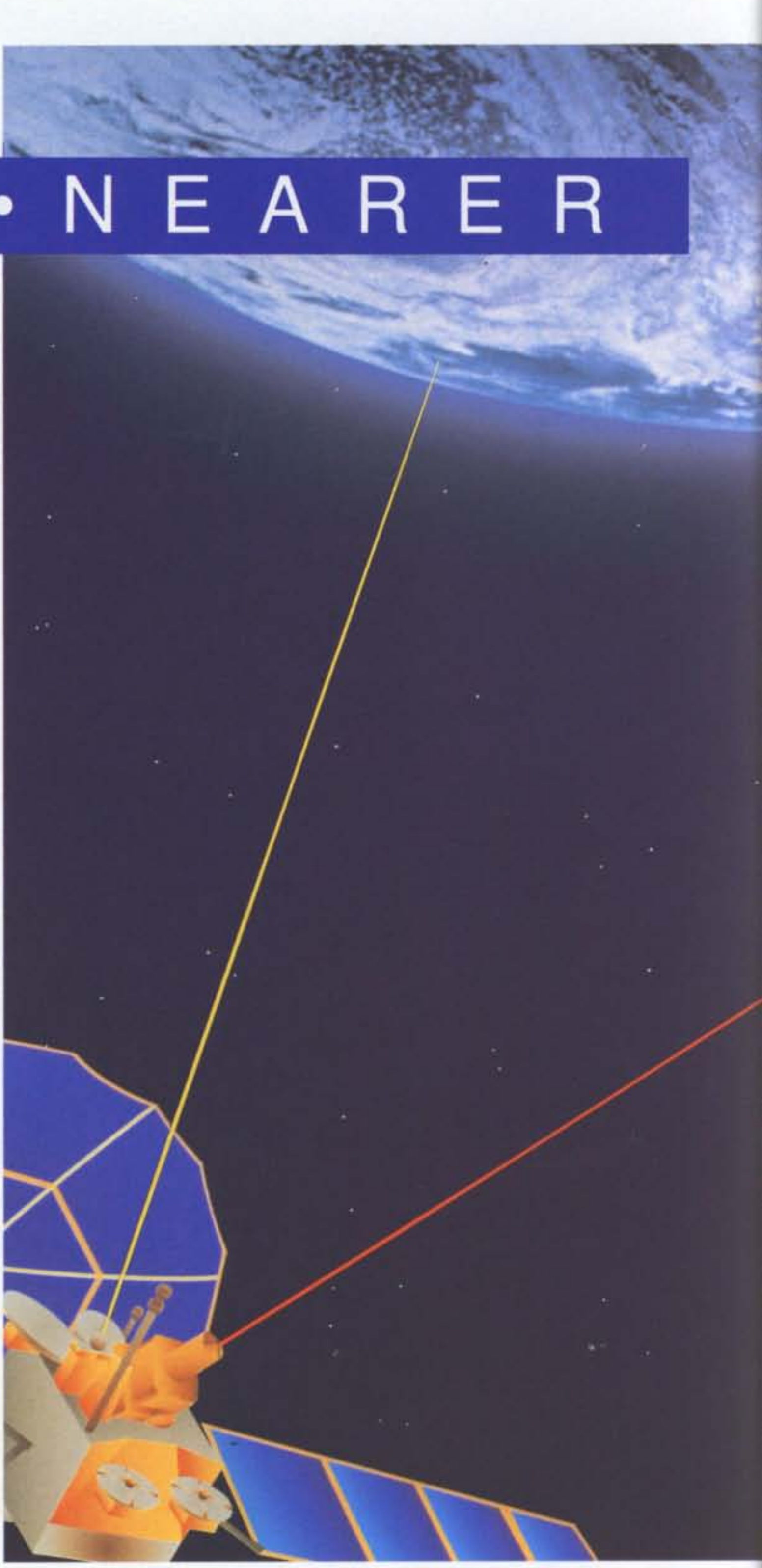

An oil spill in the Mediterranean. A typhoon over the Indian ocean. For an observation satellite, seeing accurately is sometimes not enough. Urgent information must be transmitted in real time to everyone concerned. The solution: a network of optically-linked relay satellites.

Project SILEX* will soon demonstrate in orbit this advanced inter-satellite communications technology. Laser links between an observation satellite and a telecommunications satellite will be one of the first applications of this promising field.

SILEX is one reason why two leading space companies - Matra Espace and Marconi Space Systems - have linked up in a new joint venture: Matra Marconi Space, the first international space company. The goal: a higher synergy of technology and resources that will bring future space applications nearer to reality.

** SILEX is an ESA program.*

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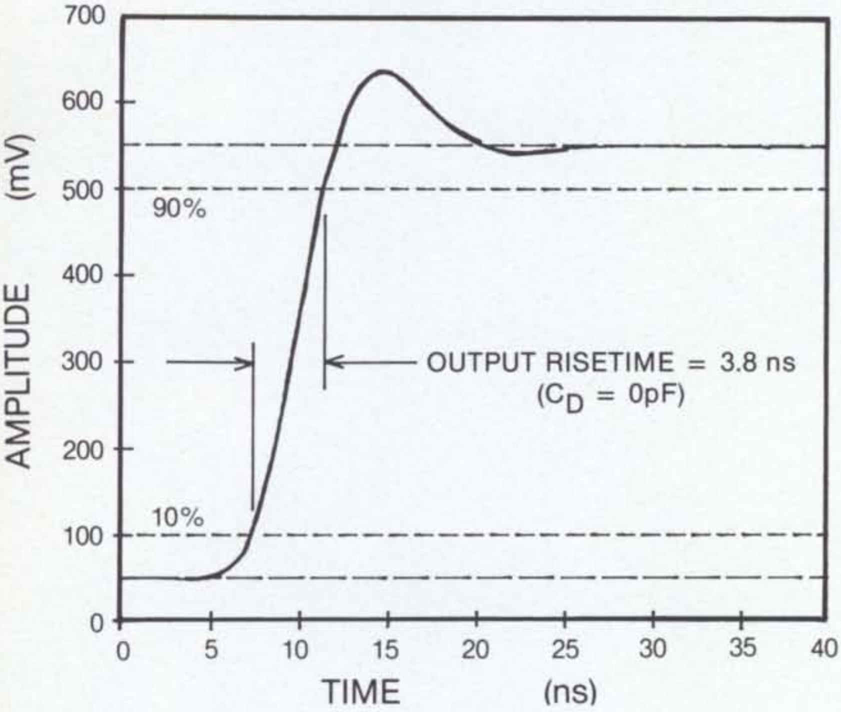
MATRA MARCONI SPACE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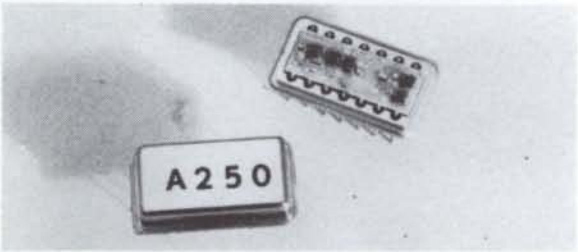
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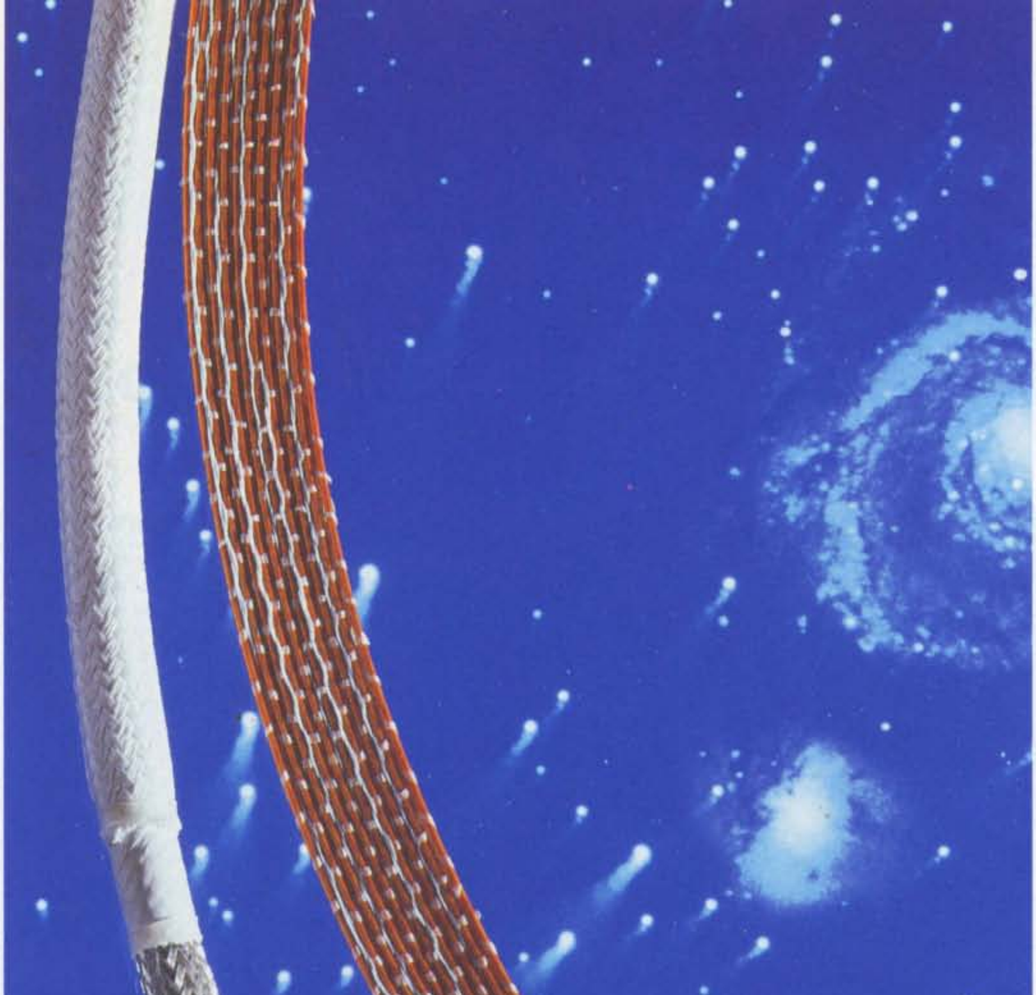

Standard cable solutions are totally inadequate in space applications. Power supply cable assemblies connect individual on-board systems and components to the on-board power supply network. Like all interconnections, they are exposed to the aggressive space environment. W.L. GORE has developed a range of cables to meet these extremes, the performance characteristics of which have become an international standard of excellence.
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Product Information:

Power Supply Cable Assemblies for Space Technology

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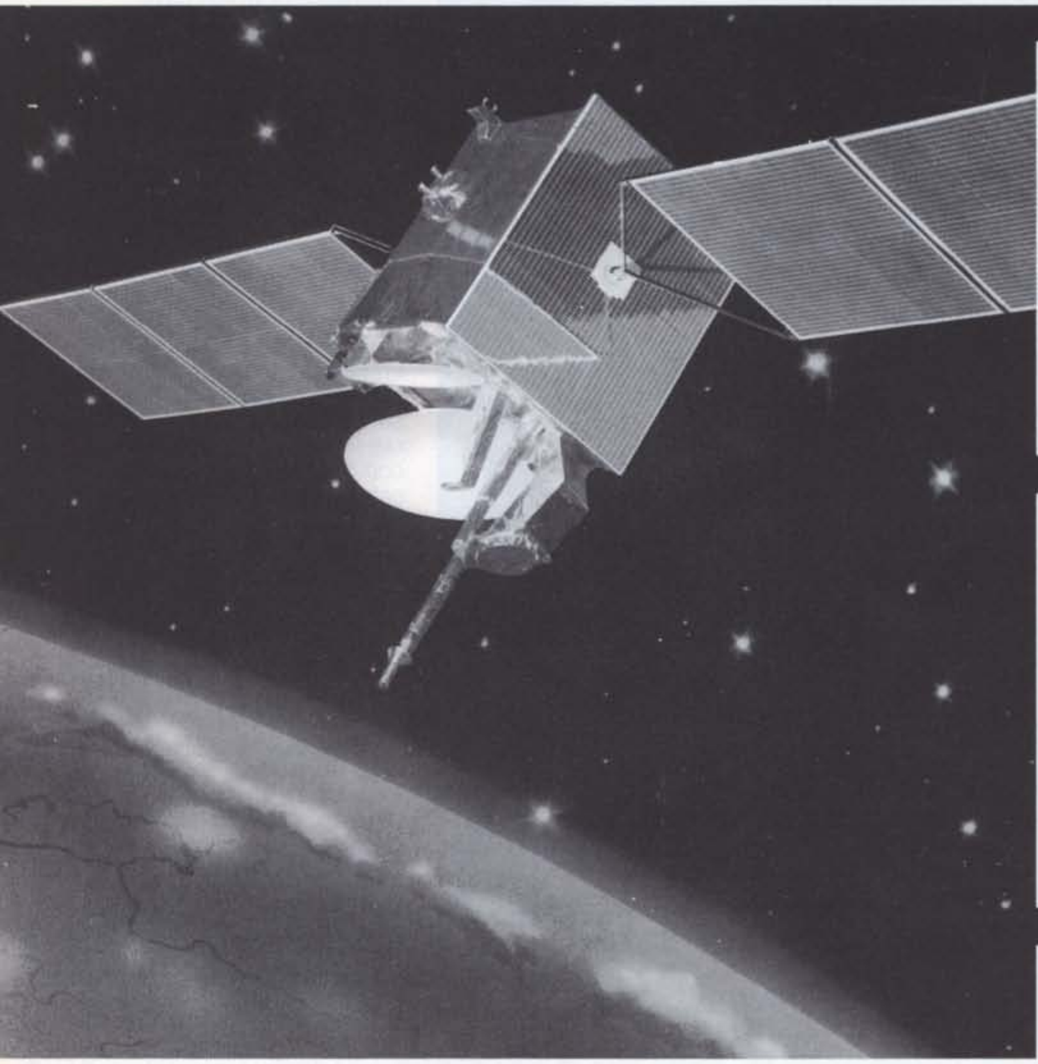
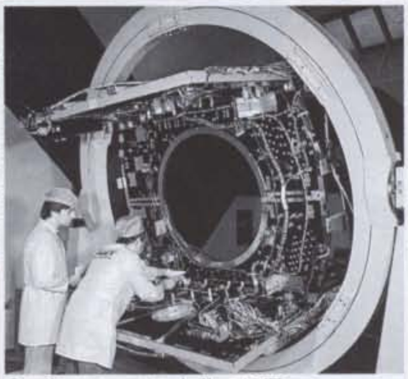
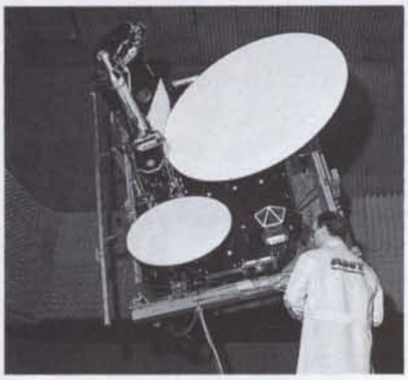
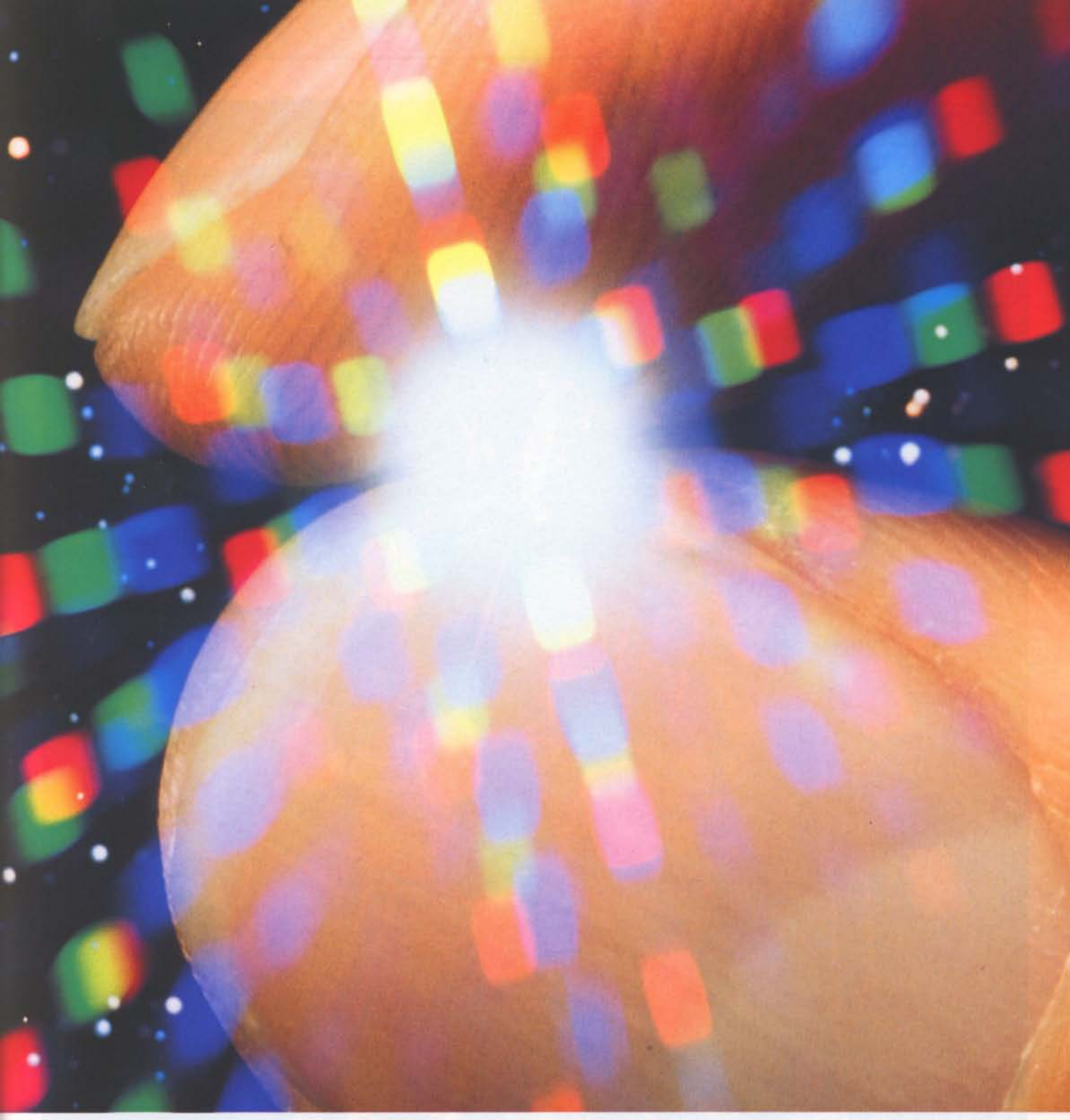




Satellite integration hall at ANT



DFS antenna module measurement



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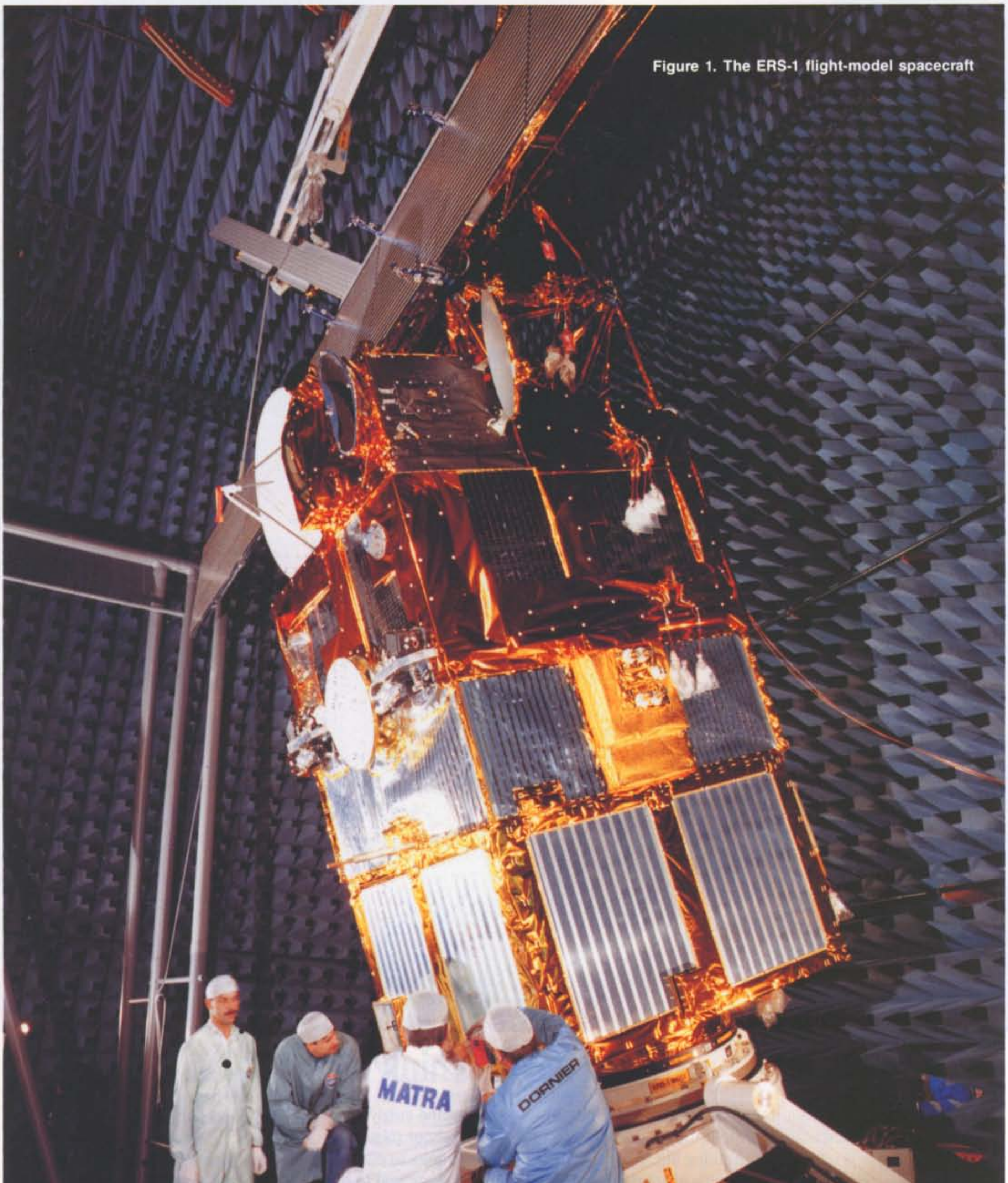


Figure 1. The ERS-1 flight-model spacecraft

ERS-1: A Contribution to Global Environmental Monitoring in the 1990s

S. Bruzzi
Directorate for Observation of the Earth and its Environment, ESA, Paris

M. Wooding
ESA Consultant, Farnborough, UK

There is increasing concern that man's activities are starting to upset the sensitive thermodynamic and ecological balance of our planet. One of the most crucial of these effects is the increase in our atmosphere's carbon-dioxide concentrations due to the burning of fossil fuels and to deforestation. It has been predicted that mean global temperatures may rise by as much as 2 or 3° C over the next 50 years. The result could be major shifts in regional weather and vegetation patterns, as well as a partial melting of the polar ice caps, with many densely populated areas becoming inundated by rising sea levels.

These major problems confronting mankind can only be addressed effectively if we understand the complexities of our global environment to a much greater degree than at present. Complex interactions have to be unravelled in order to comprehend fully the processes involved, and this requires thorough investigation of the physical behaviours of the atmosphere, oceans, ice and land-surface cover. The magnitude and rate of change of many of the processes involved cannot yet be reliably measured, let alone predicted. ERS-1, the Agency's first remote-sensing satellite, to be launched at the end of this year, will contribute, with a totally new set of measurements, to a more rapid understanding of these processes.

Introduction

Both global and repetitive observations are needed to resolve the broad range of space and time scales involved in the monitoring and preservation of our environment. These requirements are very wide-ranging, and Earth observation from space may provide some of the most viable and cost-effective means of acquiring much of the necessary input data for climate models, and for monitoring the Earth's surface conditions on local, regional and global scales on different time scales.

The first European Remote-Sensing Satellite, ERS-1, will be the forerunner of a new generation of space missions planned for the 1990s which promises to make a substantial contribution to the scientific study of our environment. It uses advanced microwave/radar techniques that will allow global measurements and imaging irrespective of cloud and sunlight conditions (such techniques have been used previously only by the short-lived Seasat mission in 1978, and during brief Space-Shuttle experiments).

In addition, it will measure many parameters not covered by existing satellite systems, including sea state, sea-surface winds, ocean circulation and sea/ice levels, as well as conducting all-weather imaging of oceans, ice and land. Significantly, much of the data will be collected from such remote areas as the polar regions and the southern oceans, for which there is currently little comparable information available.

The ERS-1 mission will therefore provide essential data for addressing a wide range of primary environmental problems, contributing to:

- improved accuracy in the representation of interactions between ocean and atmosphere in climate models
- major advances in our knowledge of ocean circulation and associated energy transfers
- more reliable estimates of the mass balance of the Arctic and Antarctic ice sheets
- better monitoring of dynamic coastal processes and pollution; and
- improved detection and management of land-use change.

ERS-1 has been designed to satisfy operational requirements for data products quickly, and it will therefore also make significant contributions to operational meteorology, sea-state forecasting and the monitoring of sea-ice for shipping and offshore activities. Land-resource management and some aspects of solid-Earth research will also benefit.

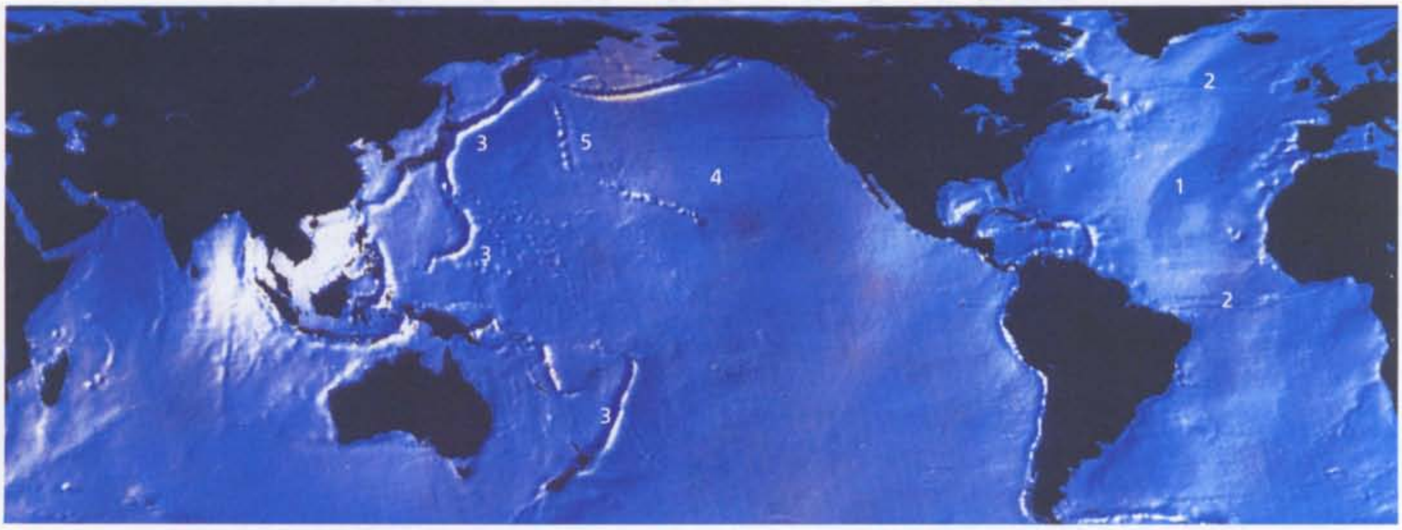


Figure 2a. Ocean-surface topography. The topography of the ocean's floor is reflected in the topography of its surface. This Seasat-derived ocean-surface relief map reveals the mid-Atlantic ridge (1) and associated fracture zones (2), the Kuril, Marianas and Tonga Trenches (3), the Hawaiian-island chain (4) and the older Emperor seamount chain (5).
(Photo courtesy of NASA)

Figure 2b. Ocean circulation. Map of variations in mean sea level over a four-week period in Sept./Oct. 1978 as measured by Seasat. The largest variations of up to 25 cm shown in red are associated with strong currents, including the Gulf Stream (6), Kuroshio (7), Agulhas (8), Falkland (9) and Antarctic Circumpolar (10) currents.
(Photo courtesy of NASA)

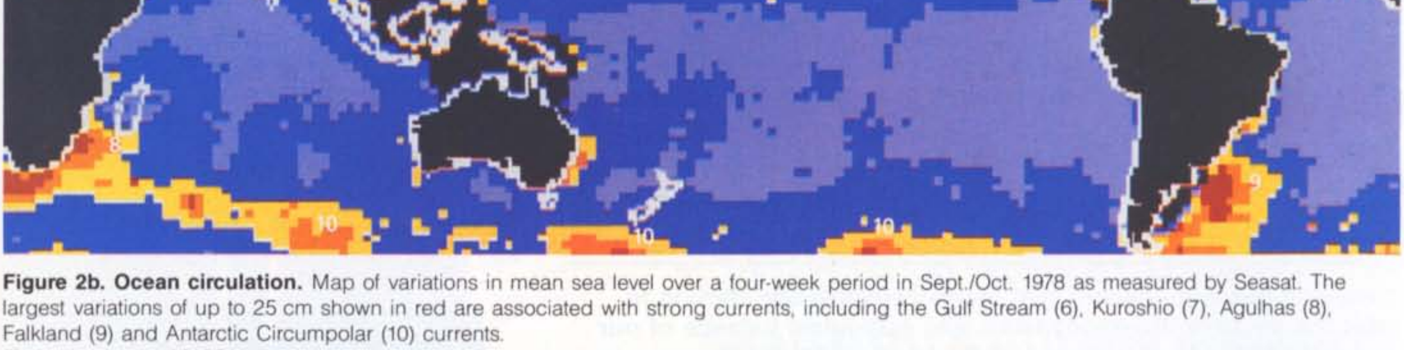


Figure 2c. Global wave height. Averaged significant wave height during the period July to September 1978 as measured by Seasat. ERS-1 will provide global wave-height measurements suitable for producing similar maps on a weekly basis.
(Courtesy of D.B. Chelton, Oregon State University and NASA/JPL)

Scientific potential

Physical oceanography and glaciology

ERS-1's ability to acquire comprehensive global data on and images of ocean and ice phenomena, where scientists have previously had to rely on sporadic and unevenly distributed measurements from ships and buoys, will have a profound effect on such disciplines as oceanography, glaciology and geodesy. Significant advances are expected in our scientific knowledge of many aspects of the ocean environment, including:

- ocean circulation, currents and tides and the propagation of internal waves
- global wind/wave relationships
- ocean-floor topography and the marine geoid
- shallow-water bathymetry
- polar ice sheets and sea ice.

Climatology

At a time when there is increasing concern that man's activities are starting to affect the sensitive climatic balance of our planet, ERS-1 data will have a particularly important role to play in the study of inter-relationships between oceanographic and climatic phenomena, and their influence on global climatic change and weather conditions. Global measurement of sea-surface winds and temperatures, ocean/atmosphere heat exchange, ocean currents, and the monitoring of the polar regions are all important in this context.

ERS-1 will also make significant contributions to the large-scale experiments of the World Climate Research Programme: the Tropical Ocean and Global Atmosphere (TOGA) for monitoring climatic anomalies, such as the El Nino and the Southern Oscillation; and the World Ocean Circulation Experiment (WOCE) for estimating and modelling the ocean's global heat and water circulation with the precision necessary for evaluating its climatic impact.

Solid-Earth

The combined use of various ERS-1 instruments, leading to accurate orbit determination, will contribute substantially to solid-Earth studies, including:

- accurate determination of the ocean geoid;
- geophysical studies of the oceanic lithosphere (e.g. tectonic, thermal and mechanical structure) and of convection in the Earth's mantle;
- precise relative geodetic positioning.

Summary of ERS-1 Geophysical Measurements and Performance Parameters

Geophysical Parameter	Range	Accuracy	Main Instrument
Wind Field			
- Velocity	4 – 24 m/s	±2 m/s or 10% whichever is greater	Wind Scatterometer & Radar Altimeter
- Direction	0 – 360°	±20°	Wind Scatterometer
Wave Field			
- Significant Wave Height	1 – 20 m	±0.5 m or 10% whichever is greater	Radar Altimeter
- Wave Direction	0 – 360°	±15°	SAR Wave Mode
- Wavelength	100 – 1000 m	20%	SAR Wave Mode
Earth Surface Imaging - Oceans - Coastal Zones - Sea-Ice - Land	100 km	Geometric/Radiometric Resolutions: a) 30 m/2.5 dB b) 100 m/1 dB	SAR Image Mode
Altitude			
- Over ocean	745 – 825 km	±10 cm	Radar Altimeter
- Polar Ice-Sheets		<1 m	
Satellite Range		±10 cm	PRARE
Sea Surface Temperature	500 km swath	±0.5 K	ATSR (IR)
Water Vapour	in 25 km spot	10%	μW Sounder

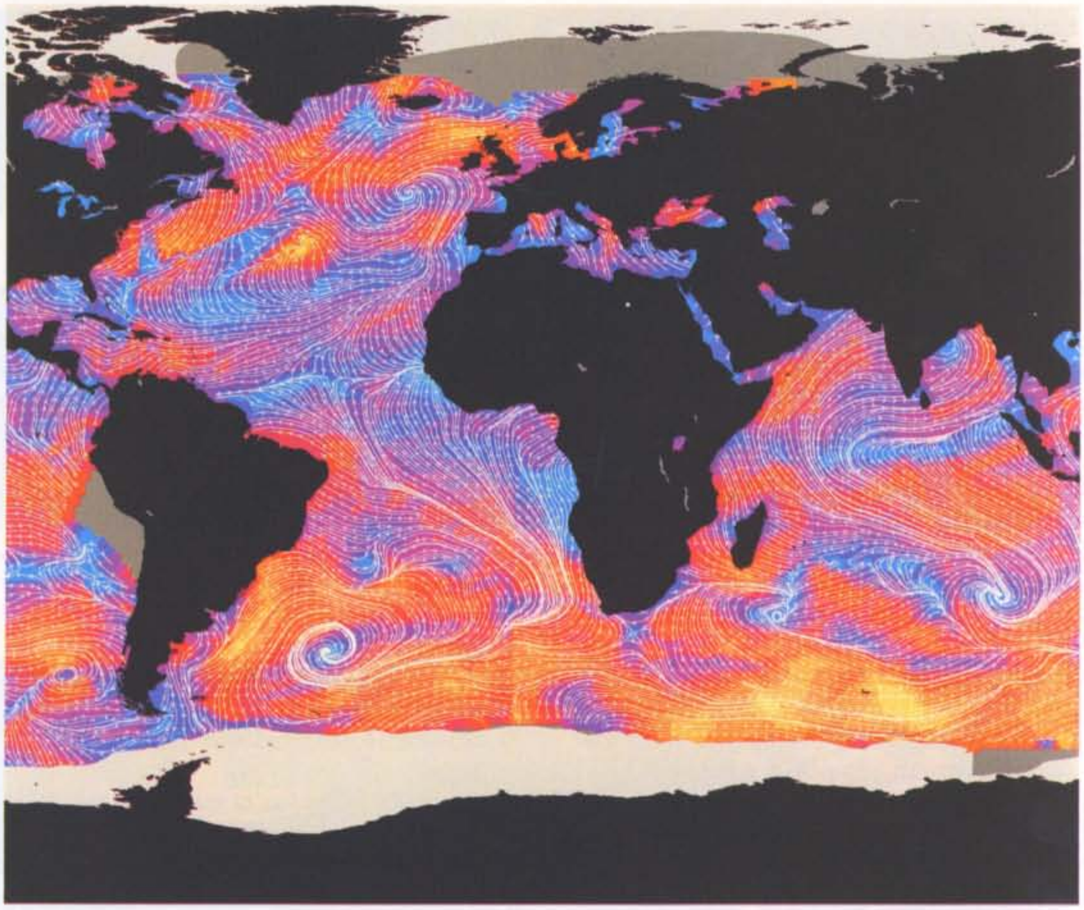


Figure 3. Large-area wind field

Surface wind field over the Atlantic on 14 September 1978, as derived from Seasat's scatterometer. (Courtesy of P. Woiceshyn, JPL, M. G. Wurtele, UCLA, & S. Peteherych, AES/CDN)

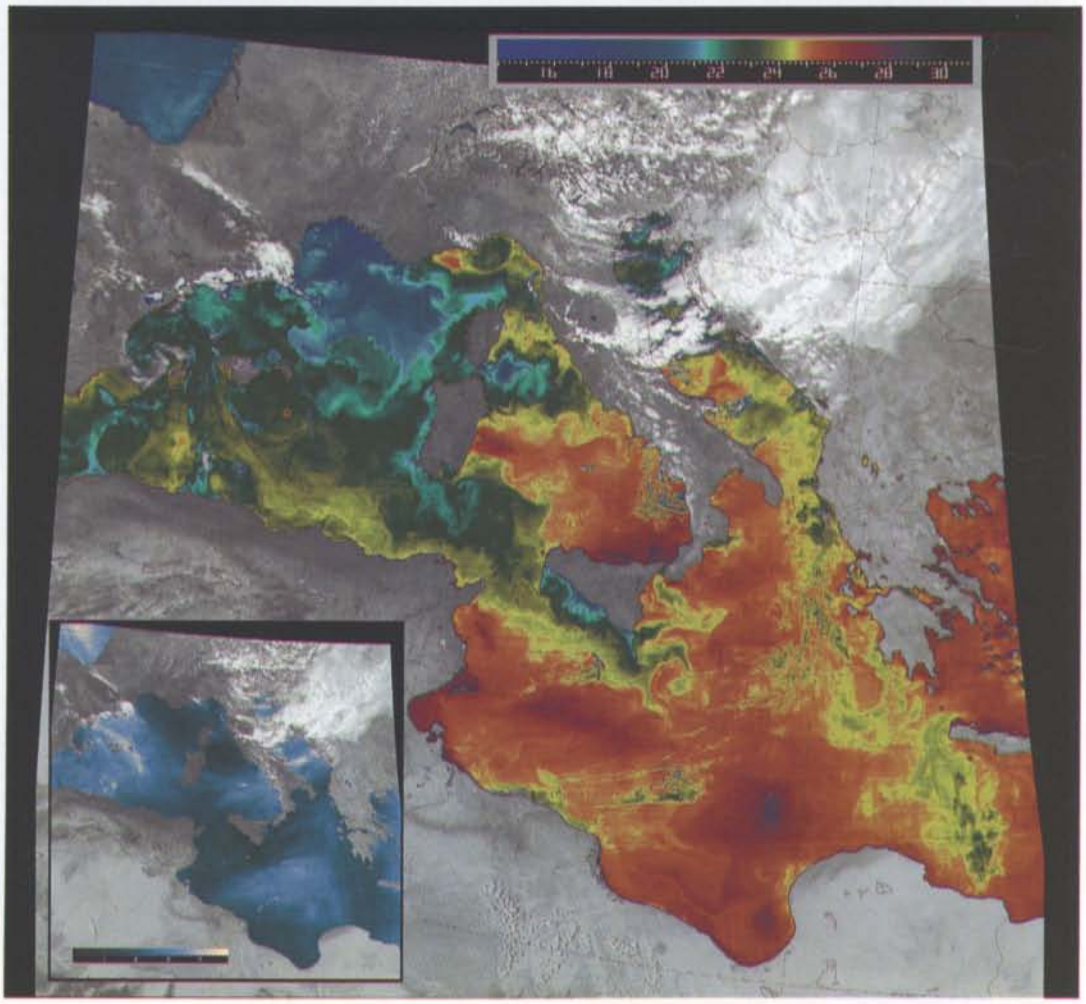


Figure 4. Sea-surface temperature

Image of sea-surface temperature of the Mediterranean on 5 August 1987 produced from AVHRR imagery, with an inset showing differences in atmospheric humidity. The ERS-1 PAFs will generate similar products to enhance the accuracy of its ATSR measurements. (Courtesy of DLR, Oberpfaffenhofen)

Coastal processes
The changing patterns of coastlines, the sea's behaviour near coasts, and sea-bed profiles, can all be monitored by a combination of ERS-1 instruments, even in otherwise inaccessible areas and in cloud-covered regions.

Operational/experimental applications

ERS-1 will provide global information in near-real-time, suitable for use in established operational systems for the forecasting of weather, sea-state and ice conditions. Significant benefits are expected through improved efficiency and safety in all ocean-related activities, including offshore exploration, ship routing, fish-resource management, and ship and offshore-equipment design.

Weather forecasting
The virtual lack of quantitative data over the open ocean has long been a major impediment to the forecasting of short- and medium-term weather developments. ERS-1 will provide weather-forecasting services with important new measurements of wind speed and direction at the sea surface, supplemented by those of sea-surface temperature and atmospheric water-vapour content.

Sea-state forecasting
Since most wave models use wind-field data as a primary input parameter, global measurements of wind speed and direction will also significantly improve the forecasting of sea conditions. Moreover, ERS-1 will provide an excellent opportunity for checking and tuning the models with direct measurements of wave height, length and direction.

Ice mapping
The all-weather, day-and-night sensing capabilities of active-microwave instruments are particularly critical in the context of polar studies, because these parts of the World are frequently obscured by clouds or fog, and are in darkness (polar night) for long periods. Regular mapping of the distribution and motion of sea ice for marine-navigation purposes, and the mapping of the extent of glacial ice and surface features for climatic studies, will both be important applications of ERS-1 data.

Pollution monitoring
Oil slicks have a damping effect on surface waves which is detectable by radar. ERS-1 will complement existing operational airborne radar systems by providing large-area monitoring of oil pollution.

Figure 5. Agriculture and forestry
Agricultural fields and a forested area (light-toned area along left edge of image) in Flevoland, The Netherlands, as seen by Seasat. ERS-1 will provide regular imaging for crop monitoring throughout the growing season. Potentially important forestry applications include forest mapping and change detection, and the discrimination of compartments of trees of different species and ages.

Ship detection
Ships and their wakes are easily detected using imaging radar. ERS-1 will therefore offer good ship-surveillance possibilities over the open oceans.

Land applications
ERS-1's imaging radar will offer excellent land-application opportunities in such disciplines as agriculture, forestry, geology and glaciology. All-weather imaging has particular benefits for crop monitoring and snow and ice studies, because of the strong requirement for frequent and reliably timed images, and the fact that adverse meteorological conditions often prevent the use of optical sensing techniques. Radar has a special sensitivity to surface-roughness characteristics and topography, which is important in the context of both forest and geological mapping.

The satellite

The ERS spacecraft platform is based on an existing design developed for the French Spot programme. It is three-axis-stabilised, with yaw steering, nadir pointing, and roll/tilt capabilities. The 11.7 x 2.4 m solar array will supply 1.8 kW of power and there are four 24 Ah batteries on board. Communications and data handling will be effected via an S-band telemetry, tracking and command (TT&C) link.

Physical Dimensions of ERS-1

Total Mass	2400 kg
Overall height	11.8 m
Solar Array	11.7 × 2.4 m
SAR Antenna	10.0 × 1.0 m
Scatterometer Antennas	
– Fore/Aft Antenna	3.6 × 0.25 m
– Mid Antenna	2.3 × 0.35 m
Radar Altimeter Antenna	1.2 m diameter

The satellite's payload is made up of:

- an Active Microwave Instrument (AMI), which will operate in three different modes
- a Radar Altimeter, which will provide accurate measurements of sea-surface elevation, significant wave heights, sea-surface wind speeds and various ice parameters
- an Along-Track Scanning Radiometer (ASTR) and Microwave Sounder, combining infrared and microwave sensors for the measurement of sea-surface temperature, cloud-top temperature, cloud cover, and atmospheric water vapour
- Precise Range and Range-Rate Equipment (PRARE), for the accurate determination of satellite position and orbit characteristics, and for geodetic 'fixing' of ground stations
- a Laser Retro-Reflector (LRR), for the measurement of satellite position and orbit using laser ranging stations on the ground.

The payload data-handling system will transmit instrument data via two X-band links. An on-board tape recorder will store low-bit-rate data from all instruments except the SAR in imaging mode.

The payload instruments

Active Microwave Instrument (AMI)

In its so-called 'SAR Image Mode', this synthetic-aperture radar will obtain strips of high-resolution imagery 100 km in width to the right of the satellite track. The 10 m-long antenna will be aligned parallel with the satellite orbit to direct a narrow radar beam sideways and downwards onto the Earth's surface over the 100 km swath. Imagery will be built up from the strength of the return signals, which depend primarily on the surface's roughness and dielectric properties.

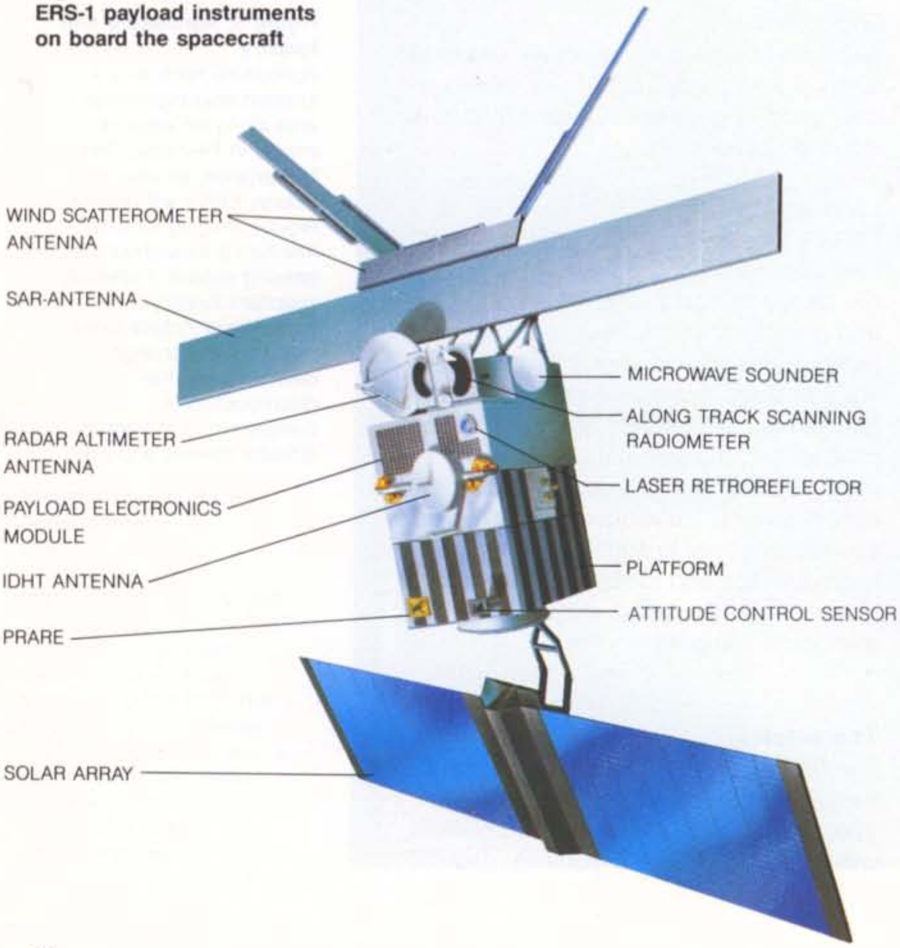
The mid-swath incidence angle of the radar will normally be 23°, but the spacecraft has a 'roll/tilt' capability allowing it to operate at 35° on an experimental basis. This increased angle of incidence is of special interest for some land applications.

Image-Mode Specifications

Frequency	5.3 GHz (C-band)
Polarisation	VV
Incidence angle	23° at mid-swath
Spatial resolution	30 m
Radiometric resolution	2.5 dB at –18 dB
Swath width	100 km
Data rate	<105 Mbps

In the so-called 'SAR Wave Mode', the AMI will provide small 5 km×5 km images, so-called 'imagettes', at 200 km intervals along track. This provides for global sampling of wave spectra suitable for the daily measure-

Figure 6. Locations of the ERS-1 payload instruments on board the spacecraft



ment of the wavelengths and directions of the main ocean swell wave systems. Sample size and sample rate have been dimensioned to give useful global data on ocean waves, but kept small enough to facilitate on-board recording and rapid data processing. Automatic processing will be carried out to derive information related to wave spectra.

Wave-Mode Specifications

Frequency	5.3 GHz (C-band)
Polarisation	VV
Incidence angle	23° / ±0.5°
Sample size	5 km × 5 km
Sample spacing	200 km
Wave direction	
– range/accuracy	0–180° / ±20°
Wave length	
– range/accuracy	100–1000 m / ±25%
Onboard range compression (optional)	10 × 5 km imagettes

In 'Wind Scatterometer Mode', three side-looking antennas (beams) – one pointing at right angles to the satellite's flight path, one pointing 45° forward, and the third pointing 45° backward – will continuously illuminate a swath 500 km wide as the satellite advances along its orbit. Each will provide radar-backscatter measurements from the sea surface for 50 km-resolution cells using a 25 km grid spacing.

Wind Scatterometer Specifications

Frequency	5.3 GHz (C-band)
Polarisation	VV
Incidence angle range	fore/aft beams 25°–59° mid beam 18°–47°
Swath width	500 km
Spatial resolution	50 km
Grid spacing	25 km
Wind direction	
– range/accuracy	0–360° / ±20°
Wind speed	
– range/accuracy	4–24 m/s / 2 m/s or 10%

The surface wind speed and direction will be calculated using these 'triplets' of measurements for each resolution cell in a mathematical model that defines the relationship between backscatter, wind speed, wind direction and incidence angle of the observation.

Wind-scatterometer operation can be interleaved with the SAR wave mode for the acquisition of wind/wave data over large ocean surfaces.

Radar Altimeter

The Radar Altimeter is a nadir-pointing pulsed radar designed to measure echoes from ocean and ice surfaces. In 'Ocean Mode' it will be used to measure wave height, wind speed and sea-surface elevation. In 'Ice Mode', it will operate with a coarser resolution to determine ice-sheet surface topography, ice type and sea/ice boundaries.

Altitude measurements are obtained from the time delay between transmission and reception of a pulse, after correction for atmospheric and other effects. Significant wave height is measured from the slope of the leading edge of the return wave form. Wind speed over sea surfaces and the location of the sea/ice boundary is derived from the power level of the return signal.

Radar Altimeter Specifications

Frequency	13.8 GHz (Ku-band)
Bandwidth	
– ocean mode	330 MHz
– ice mode	82.5 MHz
Beamwidth	1.3°
Altitude measure	
– range/accuracy	745–825 km / 10 cm
Significant wave height	
– range/accuracy	1–20 m / 0.5 m or 10%
Backscatter coefficient	
– radiometric resolution	0.7 dB rms
Echo waveform samples	64 × 16 bits at 20 Hz

ATSR

The Along-Track Scanning Radiometer (ATSR) with Microwave Sounder is a passive instrument consisting of an advanced four-channel infrared radiometer providing sea-surface and cloud-top-temperature measurements, and a two-channel microwave sounder providing information on total atmospheric water content.

The ATSR's infrared channels will deliver higher accuracies than similar instruments flown on previous satellites, thanks to its novel conical scanning technique and improved black-body calibration. The new scanning technique will allow the Earth's surface to be viewed at different angles (0° and 52°) in two 500 km-wide, curved swaths separated by about 700 km. Data from these two swaths will be combined to

ATSR Technical Specifications

IR Radiometer	
– swath width	500 km
– spectral channels	1.6, 3.7, 11 and 12 µm
– spatial resolution	1 km × 1 km
– radiometric resolution	0.1 K
– predicted accuracy	0.5 K over a 50 km × 50 km square with 80% cloud cover
Microwave Sounder	
– channels	23.8 and 36.5 GHz
– instantaneous field of view	20 km
– predicted accuracy	2 cm

provide an accurate atmospheric correction for the calculation of sea-surface temperature.

The Microwave Sounder is a nadir-viewing passive radiometer operating at 23.5 and 36.5 GHz to measure the total water content of the atmosphere within a 20 km footprint. This will help to improve the accuracy of the sea-surface-temperature measurements provided by the ATSR, and also provide accurate tropospheric range correction for the Radar Altimeter.

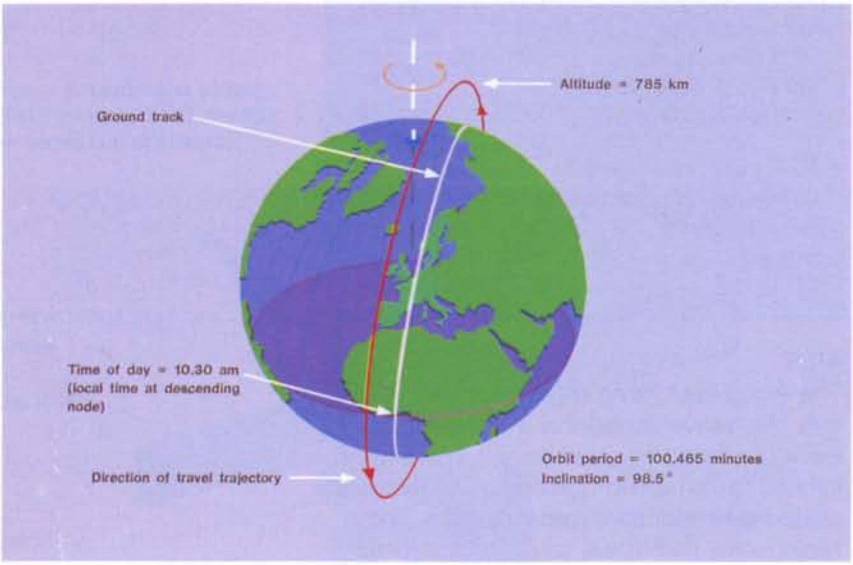


Figure 7. Geometry of the ERS-1 orbit

PRARE and Laser Retro-Reflector

The main role of these instruments will be to provide precise orbit determinations for the referencing of height measurements made by the Radar Altimeter.

The Precise Range and Range-Rate Equipment (PRARE) is an all-weather microwave ranging system, with centimetre accuracy, for the measurement of satellite-to-ground range and range rate. It relies on two-way dual-frequency measurements between the satellite and a network of small, mobile, ground tracking stations.

Orbits and coverage patterns

ERS-1 will be in a Sun-synchronous circular orbit (quasi-polar) with a mean altitude of 785 km and an inclination of 98.5°. The local mean solar time at the crossing of the equator from north to south (i.e descending node) will be 10.30 a.m.

The mission will involve a number of adjustment manoeuvres to synchronise the satellite's orbital period with various requirements for ground coverage. During the initial three-month commissioning phase, the satellite will have a 3-day repeat cycle at an altitude of 785 km, called the 'reference orbit'. Subsequent satellite height adjustments can provide various repeat cycles of between 3 and 176 days.

The majority of the rest of the mission will be performed in a 35-day repeat cycle, with some transitions back to 3 days, and a final 176-day orbit towards the end of the mission.

3-day cycle

For a satellite altitude of 785 km, the Earth's rotation causes a spacing of 909 km at the equator between successive ground tracks. After completing 43 passes in 3 days, the satellite orbit will repeat the same coverage pattern exactly.

This 3-day repeat cycle is chosen for the commissioning phase because it provides frequent revisiting of dedicated calibration sites under constant geometrical and illumination conditions. The orbit's phasing will be adjusted to provide a subsatellite track over the Radar-Altimeter calibration site near Venice, Italy.

A similar 3-day cycle will be operated for limited periods twice during the mission with slightly different longitudinal phases to give highly repetitive coverage of ice zones during Arctic winters.

35-day cycle

The main limitations of the 3-day cycle are the restricted global coverage for the imaging SAR, and the wide separation of the Radar-Altimeter tracks. A 35-day repeat cycle provides SAR imaging of every part of the Earth's surface, with at least twice this frequency of coverage at middle and high latitudes. Furthermore, the density of the Altimeter ground tracks increases to give a separation of just 39 km at 60° latitude.

176-day cycle
A 176-day cycle is favoured for measurement of the mean sea surface and ocean geoid, because of the very high density of Altimeter tracks. However, conflicts with other requirements mean that such an orbit configuration can only be employed late in the mission.

The Ground Segment
The ERS-1 Ground Segment includes facilities for satellite control and operations, and for the reception, archiving and processing of the instrument data, as well as providing services to satisfy user needs for fast and special-product delivery.

The *Earthnet ERS-1 Central Facility (EECF)* at ESRIN (Frascati, Italy) will be responsible for all user interface functions, including cataloguing, servicing of user requests, payload operation planning, scheduling of data processing and dissemination, quality control of data products, and sensor performance monitoring.

The *Mission Management & Control Centre (MMCC)* located at ESOC (Darmstadt, FRG) will carry out all satellite operations control and functional management, including instrument operational scheduling.

ESA ground stations at Kiruna (Sweden), Fucino (Italy), Gatineau (Canada) and Maspalomas (Canary Islands, Spain), will provide the main network for data acquisition and the processing/dissemination of fast-delivery products (see accompanying panel on the next page).

By arrangement with the Agency, other ground stations both within, and outside, Europe will also receive ERS-1 data, thereby extending the potential high-resolution imaging coverage.

Four *Processing and Archiving Facilities (PAFs)* located at DLR (Oberpfaffenhofen, FRG), IFREMER (Brest, France), BNSC (Farnborough, UK) and ASI (Matera, Italy), will be the main centres for the generation of offline precision products and the archiving of ERS-1 data and products.

Individual users and user centres, such as national and international meteorological services, oceanographic institutes and various research centres, will receive products directly from the ground stations and PAFs, based on requirements submitted to the ERS-1 Central Facility.

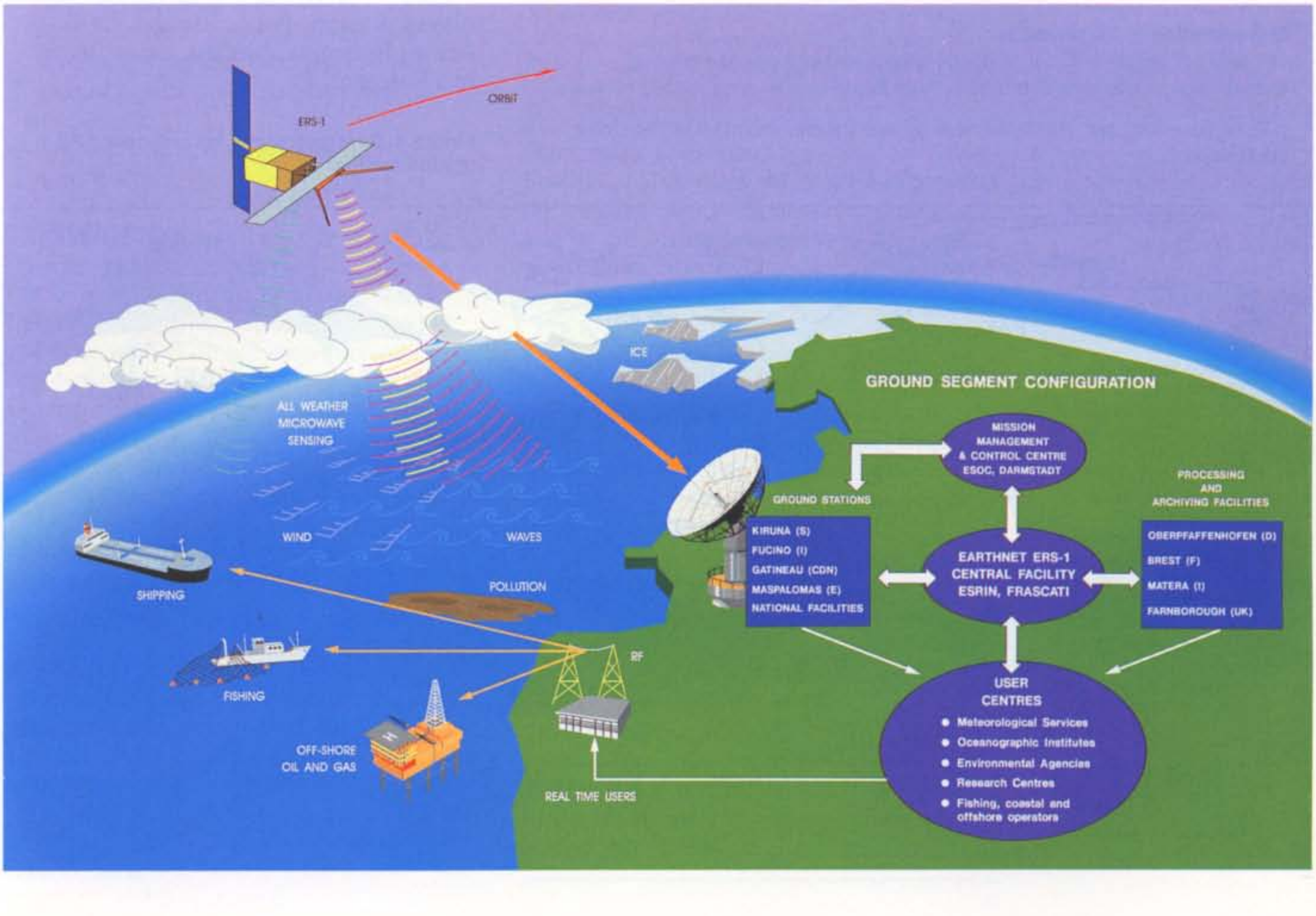


Figure 8. The ERS-1 Ground Segment and user interfaces

ERS-1 Fast-Delivery Products*

SAR Image Mode FD Product

- approx. 100 km×100 km image
- 20 m interpixel distance in ground range
- 16 m interpixel distance in azimuth direction
- available in 16 bit or 8 bit/pixel data formats.

Each SAR Fast-Delivery Processor has a throughput of three high-quality images in less than 90 min.

SAR Wave-Mode FD Product

Power spectra of 5 km×5 km 'imagettes' expressed in polar coordinates, with:

- twelve 8-bit amplitude levels in logarithmic form corresponding to spatial wavelengths between 100 m and 1000 m
- twelve angular sectors of 15° between 0° and 180°, with an angular resolution of 30°.

Each SAR Fast-Delivery Processor can generate up to 150 spectra per orbit.

Wind-Scatterometer FD Product

The scatterometer product consists of wind vectors for a grid of 19 × 19 points distributed over a 500 km × 500 km area. Wind speed and wind direction are provided for all grid points except those corresponding to resolution cells for which the percentage of land is above a given threshold.

Up to 70 of these 500 km×500 km areas can be processed between two consecutive passes.

Radar-Altimeter FD Products

Three FD products will be obtained from the Radar Altimeter, each of which are in the form of 1 s-averaged measurements (i.e. over 6.5 km on the ground).

- wind speed over the ocean
- significant wave height
- altitude over the ocean.

Processing of up to 80 data sets for 500 km sections of ground track will be possible for each orbit.

Dissemination of FD products

The SAR FD images will require a high-speed satellite data dissemination channel. Low-bit-rate data distribution will be based on the use of existing networks.

* To be generated and distributed from ground stations within 3 h of instrument observation.

Data acquisition and fast processing

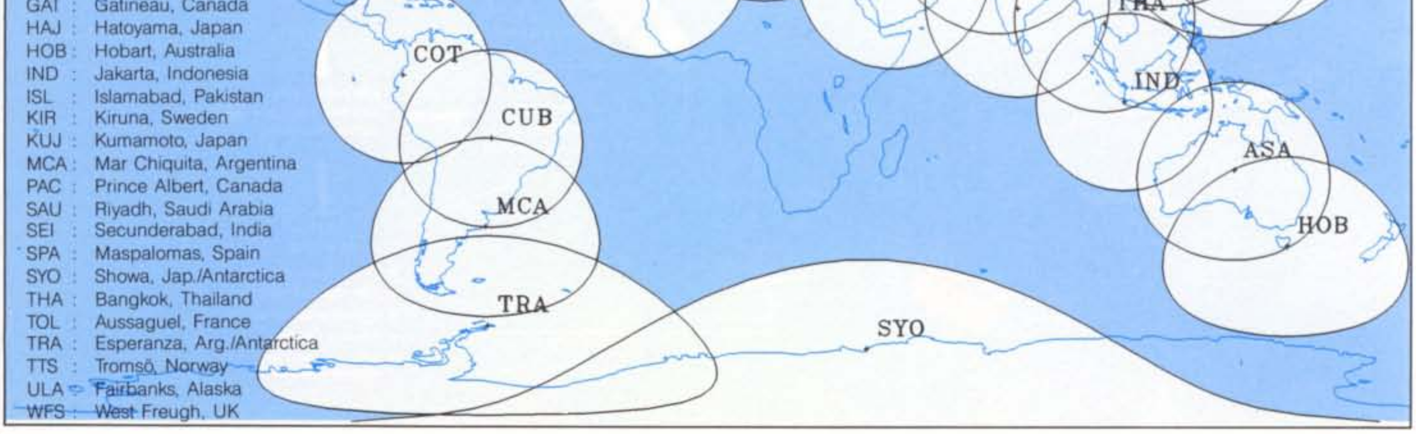
The Kiruna station in northern Sweden will play a primary role because its high-latitude location will provide visibility for ten of the satellite's fourteen daily orbits. Both instrument real-time and on-board-recorded data will be acquired by the station, with the raw data being stored on High-Density Digital Tapes (HDDTs). The fast-delivery processing facilities at Kiruna include two processing chains devoted to SAR processing (i.e. image and wave mode), and one devoted to the processing of the data from other instruments.

The Fucino station is to be used primarily for the acquisition of SAR image data and real-time low-bit-rate data acquired over the Mediterranean.

The stations at Gatineau and Maspalomas will be used for the acquisition of recorded low-bit-rate data. They, and the Fucino station, will have data-recording and fast-delivery processing facilities similar to those at Kiruna. This network of stations will therefore be able to acquire the complete global low-bit-rate dataset.

A large number of additional ground stations will increase the World coverage for SAR images. They include planned stations in Alaska, Ecuador, Brazil, Thailand, Saudi Arabia, Antarctica, Australia, Japan, India and Pakistan.

Figure 9. Coverage zones for proposed ERS-1 ground stations



There will also be additional stations in some ESA Member States, including Tromso in Norway, Aussaguel in France, and West Freugh in the UK. The Gatineau and Prince Albert stations in Canada will operate as national facilities for the acquisition of SAR data.

Processing and Archiving Facilities (PAFs)
The main functions of the four PAFs are:

- long-term archiving and retrieval of ERS-1 raw data, auxiliary information and relevant surface data
- generation and distribution of off-line geophysical and precision products
- support to long-term sensor performance assessment, calibration and geophysical validation, demonstration campaigns and pilot projects
- interfacing with the Central Facility for the updating of the catalogue, and supporting user services.

A wide variety of different off-line products will be generated by the PAFs and other national facilities to satisfy specific user requirements. These will include:

- basic products of similar quality to fast-delivery products (i.e. particularly SAR images)
- precision products using refined auxiliary data such as in-flight calibration data, precise attitude and orbit parameters, ground control points, digital elevation models, etc.
- thematic products specific to particular applications.

Earthnet ERS-1 Central Facility (EECF)
The Central User Service
The ERS-1 Central User Service will be a real-time management system dedicated to the supervision of all activities involved in ERS-1 data acquisition, product generation, and the dissemination of data and products to the user community. It will furnish: on-line tools for the definition of payload operation plans; payload data acquisition, production and dissemination management; a worldwide catalogue of data and products; and a product order-handling system.

It will also generate and make available to users a plan for the overall ERS-1 mission, including the future operations of the various instruments and ground facilities. Sections of this Plan will be constantly updated, modified and refined, based on users' requests. On-line facilities will provide the users with direct access to both the outline and detailed mission plans.

Preliminary list of off-line products

SAR
- Annotated Raw Data
- Basic Single-Look Image
- Precision Image
- Geocoded Image

AMI Wave Mode

- Precision Imagette
- Image SPectrum

AMI Wind Mode
- Sigma-nought Triplets
- Wind Field (large/local scale)

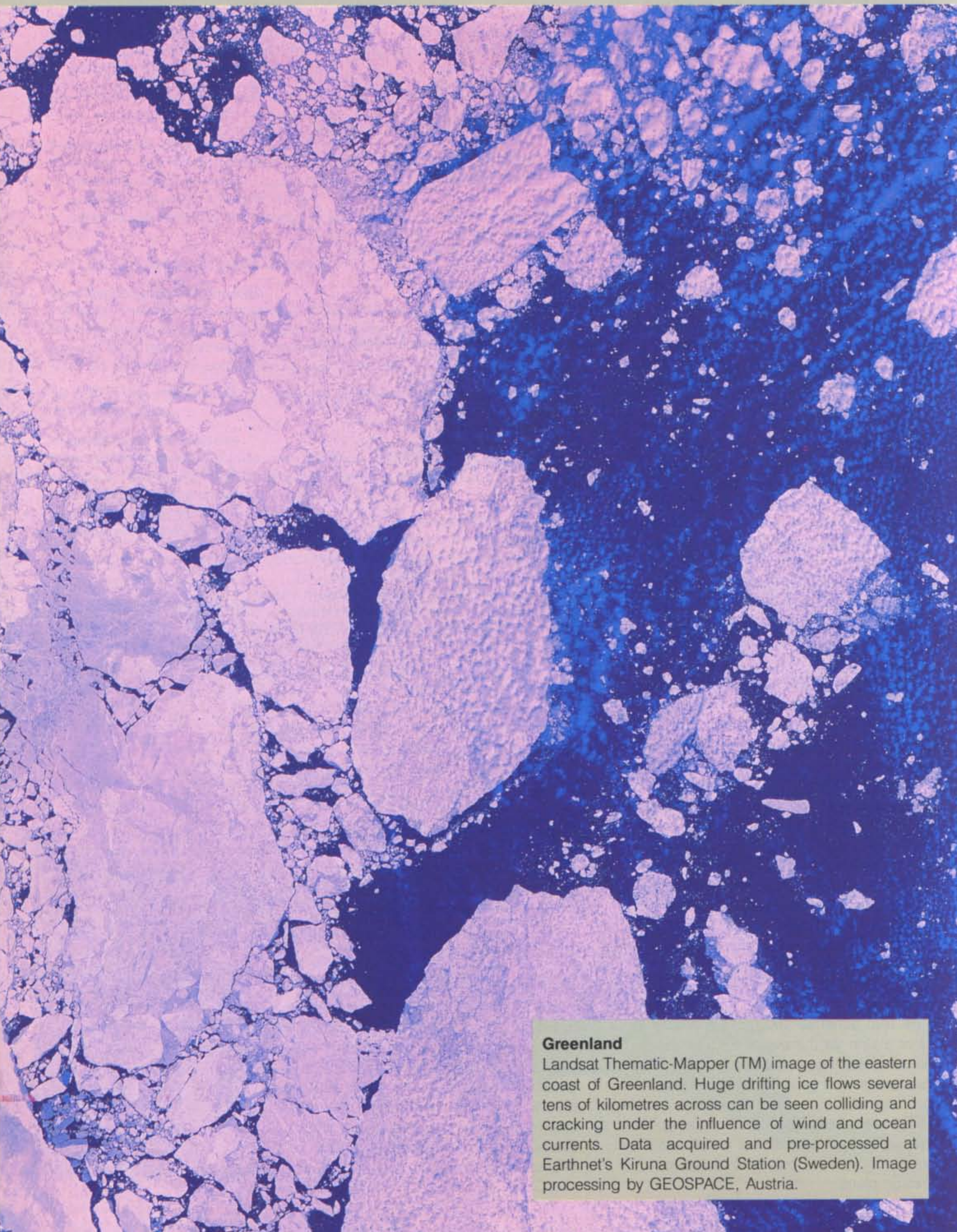
Radar Altimeter
- Sensor Record
- Ocean Product
- Augmented Ocean Product
- Sea-Ice Product
- Land-Ice Product
- Land Product
- Lake Elevation
- Sea-Surface Height
- Sea-Surface Topography
- Oceanic Geoid

ATSR
- Calibrated Radiances
- Corrected I-R Image
- Sea-Surface Temperature Image
- Cloud-Top Temperature Image
- Precision Sea-Surface Temperature Image
- Microwave Brightness Temperatures
- MW Water-Vapour & Liquid Water Content

The Central Catalogue
The ERS-1 Catalogue will provide information on the availability of all data and products, as well as the planned acquisitions. It will be available for worldwide access 24 hours per day.

The user interface will make it possible, for instance, to identify rapidly all data products derived from a specific instrument for a particular area within any specified time frame. Most searches will allow direct geographical referencing based on latitude and longitude coordinates.

The Browse Facility
The Browse Facility is a local service at ESRIN in Frascati (I) which will allow visitors access to the Central Catalogue. It will provide demonstrations of the ERS-1 system's capabilities and products. It will also provide a centralised archiving facility for mission, system and user documentation, and make available sample products and mission-related information.



Greenland

Landsat Thematic-Mapper (TM) image of the eastern coast of Greenland. Huge drifting ice flows several tens of kilometres across can be seen colliding and cracking under the influence of wind and ocean currents. Data acquired and pre-processed at Earthnet's Kiruna Ground Station (Sweden). Image processing by GEOSPACE, Austria.

Brittany

Landsat Thematic-Mapper image of the northwestern coast of France, with its sunken coastal valleys invaded by the Atlantic. The patchwork of fields reveals a favourable mixture of grassland and agriculture. The town in the lower centre is Brest. Data acquired and pre-processed at Earthnet's Fucino Ground Station (Italy). Image processing by GEOSPACE, Austria.

ESA Point of Contact

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Vue d'artiste des éléments en vol du programme Columbus et de la Station Spatiale Freedom

La promotion de l'utilisation de Columbus*

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Columbus ouvre une ère nouvelle de l'utilisation de l'espace, de par sa taille, la quantité et la diversité des ressources qu'il offre, sa présence permanente, et le nombre de ses utilisateurs potentiels.

Columbus est donc une chance pour les utilisateurs: pour les utilisateurs confirmés de l'espace, il offre la continuité de services sans laquelle il n'y a ni science ni applications; pour les utilisateurs potentiels dans des domaines non consacrés, il canalise et renforce les besoins d'une démonstration de l'intérêt (ou du non-intérêt) de ces domaines d'utilisation en fixant un rendez-vous important: le début des opérations Columbus pour lequel les domaines d'utilisation devront être clairement identifiés.

Cependant, cette chance ne pourra se concrétiser que si, d'ici à la mise en service opérationnelle de Columbus, on identifie, on informe et on prépare les utilisateurs: c'est l'objectif de la promotion de l'utilisation de Columbus.

Le programme Columbus et son utilisation

Columbus est la contribution de l'Agence spatiale européenne au projet de Station spatiale 'Freedom', cette dernière devant être composée d'une base habitée fournie par les Etats-Unis et d'éléments fournis par l'Europe, le Japon et le Canada. La Station Freedom sera lancée et assemblée en orbite à partir de 1995.

L'objectif principal du programme Columbus est de proposer aux utilisateurs européens et internationaux une infrastructure en orbite et au sol qui puisse répondre à leurs futurs besoins. De plus, ce programme permettra à l'Europe de mener à bien une coopération fructueuse avec ses partenaires internationaux, tout en représentant un premier pas vers l'autonomie européenne en matière de vols habités.

Le programme Columbus est composé de trois éléments:

— le Laboratoire attaché (Columbus Attached Laboratory) est connecté en permanence à la Station Freedom, c'est un module pressurisé composé de quatre segments de type Spacelab;

— le Laboratoire autonome (Columbus Free-Flying Laboratory) qui coorbite avec la Station Freedom, fonctionne en automatique pendant des périodes de six mois et est desservi deux fois par an, soit par l'avion spatial Hermès, soit à la Station spatiale Freedom;

— la Plate-forme polaire (Columbus Polar Platform) est une plate-forme automatique transportant essentiellement des instruments d'observation de la Terre.

Ces trois éléments réalisent donc un bon équilibre entre éléments automatiques et éléments habités, et peuvent ainsi répondre aux besoins très divers des utilisateurs.

Les motivations qui sont à l'origine du programme Columbus dépassent les seuls besoins en utilisation, elles sont aussi politiques (équilibre entre la coopération du monde occidental et l'autonomie européenne), stratégiques (disposer de la technologie et des outils du futur) et industrielles (confirmer et renforcer la maturité de l'industrie spatiale européenne, après les succès des programmes Ariane et Spacelab).

L'objectif final est cependant d'utiliser cette infrastructure et d'en tirer le meilleur bénéfice, c'est-à-dire d'avoir des utilisateurs et de les satisfaire.

L'utilisation d'une Station spatiale peut être de nature très diverse: relais de transport pour des missions plus lointaines, zone d'assemblage pour des structures très grandes, station-service pour des satellites en orbite basse ou laboratoire pour des expériences scientifiques, des essais technologiques et la mise au point de procédés de fabrication. Il n'y a pas a priori d'utilisation privilégiée, mais au moins dans

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* In German on page 33.

sa période initiale l'utilisation de Columbus sera consacrée à des activités de laboratoire, que ce soit à l'intérieur de la zone pressurisée ou à l'extérieur, avec des instruments attachés à l'infrastructure ou autonomes et coorbitants, contrôlés à partir de la Station.

Quel que soit le type d'instruments ou d'essais, l'intérêt essentiel d'une Station spatiale est d'éviter le transport d'infrastructure à travers l'atmosphère chaque fois qu'on veut utiliser l'environnement spatial: l'infrastructure est maintenue en orbite, le transport est donc limité à la seule charge utile, ce qui représente une économie importante quand on sait que la moitié des coûts des activités spatiales est liée au transport à travers l'atmosphère. (Pour fixer les idées, le laboratoire habité Spacelab a une masse au décollage de 14 tonnes pour seulement 2 tonnes de charge utile, la plate-forme automatique Eureca a une masse de décollage de 4,5 tonnes pour seulement 1 tonne de charge utile).

Figure 1. Maquette de l'intérieur du Laboratoire attaché en grandeur nature. Dr Wubbo Ockels, un des astronautes européens, fait basculer un des racks qui composeront l'aménagement du laboratoire

Malgré cet argument de base, la promotion de l'utilisation de Columbus n'est pas simple parce que:

- le calendrier est tel que Columbus ne sera pas opérationnel avant huit ans et qu'il est difficile d'intéresser des utilisateurs actuels à si longue échéance;
- la durée de vie de Columbus (30 ans) est telle que plusieurs générations d'utilisateurs se succèderont et auront des besoins différents;
- les capacités de Columbus et plus généralement de la Station spatiale sont telles que le nombre d'utilisateurs à un instant donné se chiffrera par centaines et que les motivations de chacun seront bien différentes.

Il est donc difficile de définir une stratégie de promotion quand on ne connaît pas bien la cible. C'est pourquoi la promotion ne suffira pas pour assurer le succès de l'utilisation de Columbus.

Il faut d'abord développer un système Columbus qui soit *suffisamment flexible* pour pouvoir répondre à des besoins divers et évolutifs de la part des utilisateurs.

C'est la notion même de 'laboratoire' telle qu'elle existe sur Terre: un laboratoire offre de l'espace afin d'aménager des instruments, et des ressources (puissance électrique, ordinateurs, techniciens de laboratoire, etc.) permettant de faire fonctionner ces instruments. Le type d'instrument et d'expérience dépend des utilisateurs du laboratoire qui vont se succéder au cours du temps. En plus des ressources qu'il offre aux utilisateurs, le laboratoire peut aussi offrir un environnement particulier, c'est le cas des laboratoires placés dans l'Antarctique ou sous la mer, c'est aussi le cas d'un laboratoire spatial. L'environnement spatial se caractérise en effet par trois particularités uniques: altitude importante, vide de capacité infinie, microgravité de longue durée.

Pour pouvoir faire face à des besoins différents et encore mal ciblés, un laboratoire doit être flexible, ce qui dans le cas d'un laboratoire spatial se traduit par la possibilité de reconfiguration et par une certaine autonomie de chaque utilisateur (acquise par la décentralisation des opérations et par la possibilité d'interaction entre l'utilisateur au sol et son instrument en orbite — concept de 'téléscience'). Pour être efficace, un laboratoire doit offrir des ressources d'utilisation cohérentes avec le volume d'accueil des expériences, en particulier les capacités d'opérations des instruments à bord (par astronaute, par robot, par automatisme), doivent être à la hauteur du nombre et du type d'instruments. Pour tirer le meilleur bénéfice de son environnement, un laboratoire doit être équipé de moyens de mesure quantitative de cet environnement, en particulier le niveau et la direction de microgravité doivent être connus à l'endroit de chaque expérience.

Il faut ensuite développer un système

Columbus qui soit *facilement accessible aux utilisateurs*, du scientifique isolé à la grande industrie.

L'accès facile comporte plusieurs aspects dont les plus importants sont:

- accès pour les utilisateurs européens à toutes les possibilités offertes non seulement par Columbus mais aussi par la Station spatiale Freedom. Le Protocole d'Accord de la Station spatiale limite l'accès pour les Européens au seul Laboratoire Columbus, c'est-à-dire à un domaine pressurisé et fermé à l'espace sauf par l'intermédiaire du sas scientifique pour de petits instruments, mais autorise l'accès aux points d'attache d'instruments extérieurs ainsi qu'aux laboratoires américain et japonais par troc ou par paiement. Cet accès vers l'extérieur est important et toutes les conditions doivent être mises en oeuvre pour qu'il soit possible et régulièrement effectué par échange avec l'utilisation d'une partie du Laboratoire Autonome Columbus ou par la fourniture par l'Europe d'équipements (système de pointage, système de mesure de l'environnement);
- planification rapide des expériences, qui permette de prendre en compte au plus vite les demandes et les besoins des utilisateurs;
- disponibilité du système Columbus, afin de limiter les délais d'accès et de retour des expériences et de leurs résultats. La continuité du service et la fréquence des allers et retours entre la Terre et Columbus sont des éléments essentiels de l'intérêt de la Station spatiale;
- support aux utilisateurs dans la préparation au sol des instruments et des expériences, et durant les opérations en vol. Ce support doit être assuré par des centres spécialisés dont les experts évitent à l'utilisateur d'avoir à résoudre lui-même les problèmes liés à l'environnement spatial, pour pouvoir se concentrer sur les aspects scientifiques et techniques de l'expérience. Ce support sera d'autant plus nécessaire que la communauté des utilisateurs de Columbus dépassera le cadre des utilisateurs traditionnels de l'espace;
- politique de prix attractive, associée à un processus clair de sélection des expériences. L'utilisateur qui paie tout ou partie des coûts d'une expérience spatiale doit avoir une connaissance précise de ce qu'il achète, et des droits et devoirs associés aux différents taux de participation aux frais qui lui seront proposés. Le chercheur de base sera largement aidé financièrement et en contrepartie, il sera sélectionné sur le seul mérite scientifique de l'expérience qu'il propose; il aura l'obligation de publier les résultats de son expérience. L'industriel en situation de concurrence devra payer une partie significative des coûts d'opérations s'il veut échapper au processus de sélection scientifique et garder ses résultats confidentiels;
- législation adaptée au cadre particulier d'une Station spatiale internationale où une expérience européenne peut être réalisée par un astronaute américain dans un laboratoire japonais. La protection du 'savoir faire' et des résultats doit être assurée, la politique de brevets doit sauvegarder l'intérêt de toutes les parties concernées.

Figure 2. Vue d'Hermès arrimé au Laboratoire autonome

Tous ces objectifs font l'objet d'activités dans le cadre de la préparation de l'utilisation de Columbus.

Ces objectifs étant supposés atteints, la promotion de l'utilisation doit permettre de bâtir une communauté d'utilisateurs en les convainquant que leurs besoins trouvent une réponse efficace par l'intermédiaire de la Station.

La promotion de l'utilisation de Columbus

La promotion de l'utilisation comprend deux niveaux indispensables et complémentaires:

- l'information allant vers et venant de l'ensemble des utilisateurs possibles;
- des activités préparatoires qui permettent d'associer concrètement, aussitôt que possible, les utilisateurs et Columbus.

Promotion par l'information

Quelle information?
L'information délivrée aux utilisateurs potentiels est essentielle puisque c'est à travers elle que ceux-ci pourront connaître le système en orbite et les avantages qu'il est possible d'en tirer.

Cette information comporte plusieurs étapes, du domaine le plus général à celui le plus scientifique:
- l'espace et les caractéristiques de cet environnement;
- le système Columbus, la Station spatiale, les ressources qu'ils offrent et les conditions d'accès;
- les domaines scientifiques et techniques qui peuvent bénéficier de l'environnement spatial;
- une base de données de résultats d'expérience par domaine scientifique.

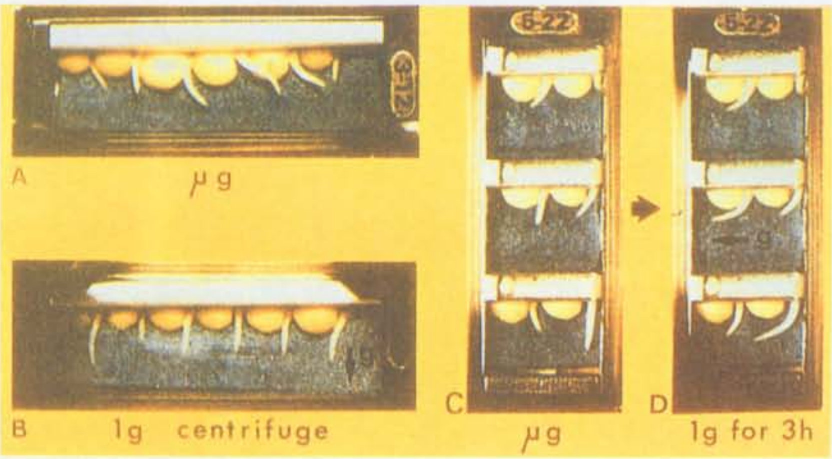


Figure 3. Les racines qui se sont développées dans des conditions de microgravité lors de la mission Spacelab-D1 font apparaître une orientation aléatoire (en haut à gauche) par rapport à celles qui ont poussé dans des conditions de 1 g (en bas à gauche). (Reproduit avec l'autorisation du Dr G. Perbal)

Cette base de données scientifiques est particulièrement importante puisqu'elle constitue la preuve objective et concrète de l'intérêt de l'environnement spatial. Cette information est pour l'instant rare et éparse. Il y a un réel besoin de la rassembler et ce au niveau international: une coordination entre toutes les agences concernées est en cours et devrait améliorer la situation actuelle.

Les moyens d'information
Les moyens sont classiques et non spécifiques au domaine spatial. Ils vont des réunions et ateliers de travail au cours desquels des échanges de vue directs ont lieu entre les 'vendeurs' et les 'clients', aux systèmes électroniques qui offrent des capacités d'information importantes, de transmissions multiples et d'interactions entre les utilisateurs. Parmi ces moyens, les documents ont encore leur intérêt comme première étape d'information ou comme support à des échanges en réunions.

En plus des moyens classiques, la présentation de matériels de vol, en particulier de charges utiles avec leurs interfaces, et l'accès à des simulateurs fonctionnels, en particulier celui de la gestion de données à bord, permettront à l'utilisateur potentiel de se familiariser concrètement avec le système en orbite, ses interfaces et les capacités qu'il offre. Cette participation active et concrète du futur utilisateur à ce stade de la familiarisation lui permet d'être associé très tôt aux différentes étapes de la préparation de la mission.

Ces moyens d'information doivent être aussi décentralisés que possible, pour être aussi proches que possible de tout utilisateur potentiel, et pour ainsi éviter que les premiers pas de l'utilisateur vers Columbus ne soient trop longs.

Information vers qui?
Etant donné que:

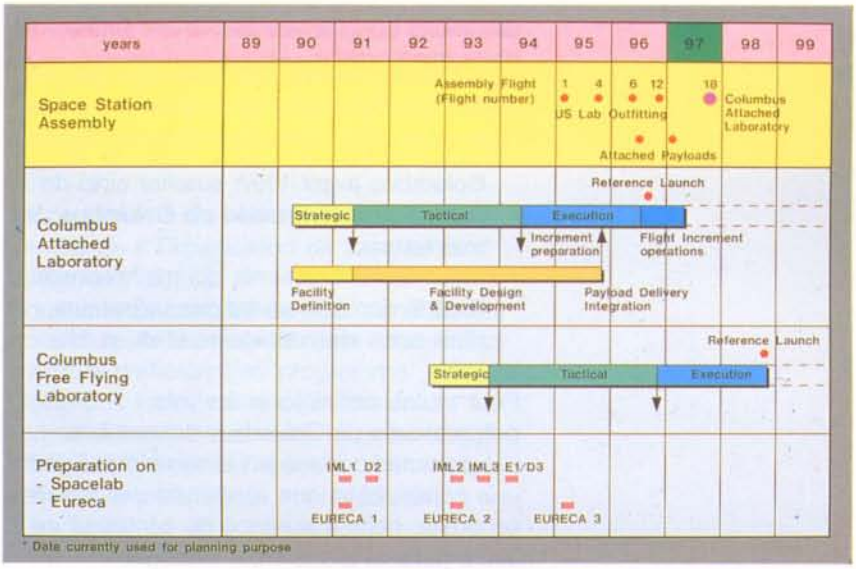
- l'échelle de temps correspondant à l'utilisation opérationnelle de Columbus s'étend de 1997 à 2027,
- les capacités offertes par Columbus représentent une augmentation d'un facteur 10 à 100 par rapport aux capacités des infrastructures spatiales actuelles,
- il n'y a pas aujourd'hui de communauté organisée d'utilisateurs,

il ne faut exclure a priori aucun utilisateur potentiel.

La promotion doit donc être faite vers toutes les catégories d'utilisateurs, du chercheur de base à l'industriel d'applications, de l'utilisateur de la microgravité au physicien stellaire, du domaine spatial au domaine industriel traditionnel.

Cependant, pour éviter une trop grande dispersion des efforts et des actions prématurées qui pourraient se révéler nuisibles, les activités de promotion doivent être organisées par étapes successives, visant à approcher les différents utilisateurs potentiels dans un ordre logique.

Dans les domaines pour lesquels l'intérêt d'utiliser l'espace est déjà clairement démontré — observation de l'espace et de la Terre — et pour des essais de validation de technologies de l'espace — déploiements d'antennes, essais de senseurs d'environnement, etc. — la promotion consiste à montrer aux clients potentiels l'intérêt d'utiliser Columbus et la Station spatiale plutôt qu'un autre véhicule, soit



* Date currently used for planning purpose

Figure 4. Planning d'utilisation des éléments Columbus

grâce à leur disponibilité permettant des délais courts entre la décision de voler et le vol lui-même, soit grâce à des coûts plus bas parce que l'infrastructure existe déjà, soit grâce à leur taille permettant l'aménagement de grands instruments, ou de plusieurs instruments en parallèle, soit grâce à la présence permanente d'astronautes.

Dans les domaines pour lesquels l'intérêt d'utiliser l'espace n'est pas encore définitivement consacré, une phase de démonstration est nécessaire au cours de laquelle il s'agira d'accumuler et de répéter des expériences et des résultats probants. C'est le cas des domaines de l'utilisation de la microgravité et du vide (dans ce dernier cas, sont incluses les applications 'solaires'). Cette phase de démonstration est déjà commencée mais s'étendra au moins jusqu'à la phase initiale des opérations Columbus. Cette phase de démonstration est avant tout du domaine de la recherche de base, c'est pourquoi la promotion doit être d'abord concentrée vers la communauté scientifique avec un effort particulier vers les étudiants chercheurs, et vers les services de recherche de l'industrie. L'adhésion du monde scientifique est importante car c'est la condition nécessaire pour que des progrès dans la connaissance scientifique soient réalisés et reconnus. L'association de l'industrie à cette phase de démonstration est également utile, non seulement pour qu'elle soit informée des développements scientifiques, mais aussi pour qu'elle puisse orienter les axes de recherche en fonction de ses besoins.

Information par qui?
La promotion de Columbus est l'affaire de tous: l'Agence spatiale européenne, les Agences nationales, des organismes spécialisés tels que Intospace et Novespace et surtout les utilisateurs déjà engagés dans les activités préparatoires. C'est surtout encouragés par la satisfaction des utilisateurs actuels que viendront les autres utilisateurs.

Pour qu'aucun utilisateur potentiel ne soit exclu de la distribution des informations, il faut décentraliser cette distribution. Aussi est-ce à l'Agence spatiale européenne et aux Agences nationales de créer l'information et de développer les outils d'information; mais c'est aux organismes nationaux, publics et privés, de disséminer cette information dans leur pays, à travers les circuits existants tels que les associations scientifiques ou les groupements professionnels. Le témoignage des utilisateurs actuels est essentiel, l'ESA et les Agences spatiales se devant de les préparer et de les aider à cette activité d'information.

Promotion par des activités de préparation
Un scientifique, un chercheur, un ingénieur, un étudiant ne deviennent utilisateurs que s'ils ont l'occasion de faire des expériences, c'est pourquoi le seul moyen de bâtir un noyau d'utilisateurs avant que Columbus ne devienne opérationnel est de fournir des occasions de réaliser des expériences, au sol et en orbite.

Les activités au sol et en orbite sont toutes deux nécessaires et sont complémentaires: les activités au sol qui incluent les essais en tour à chute libre et en vols paraboliques permettent de préparer les instruments et les expériences qui seront ensuite utilisés en orbite; les activités en orbite permettent de bénéficier de l'environnement spécifique offert par l'espace et d'en démontrer l'intérêt dans les domaines où c'est encore nécessaire.

Les activités au sol comportent des recherches scientifiques relatives aux expériences, des activités technologiques relatives à l'instrumentation et des activités liées aux opérations comme par exemple l'interaction à distance entre un utilisateur et son expérience (concept de téléscience).

Les activités en orbite constituent l'objectif ultime de l'ensemble des activités préparatoires, et bien que limitées en nombre jusqu'au début des opérations de Columbus, elles ont un rôle essentiel pour:

- renforcer et organiser un noyau initial d'utilisateurs pour Columbus;
- obtenir des résultats d'expériences scientifiquement solides dans des

domaines non consacrés comme l'utilisation de la microgravité;

— rendre le concept de Station spatiale plus accessible et plus proche dans le temps en faisant voler des expériences de type Columbus avant 1997; susciter ainsi de l'intérêt pour l'utilisation de Columbus dès maintenant;

— créer des événements qui maintiennent l'intérêt non seulement des utilisateurs, mais aussi des décideurs et du public.

Pour toutes ces raisons, les vols préparatoires de Columbus doivent être programmés comme un ensemble assurant une continuité et une répétitivité des activités en orbite: cette assurance de continuité est seule garante d'une vraie stratégie scientifique et d'une progression cohérente vers l'utilisation de Columbus.

Figure 5. Ulf Merbold, un des astronautes européens, accomplit une de ses nombreuses tâches pendant la mission Spacelab

Les vols préparatoires doivent être pour l'instant programmés sur la base de l'infrastructure orbitale disponible pour l'Europe: la plate-forme automatique Eureca dont le premier vol aura lieu en 1991 et le laboratoire spatial habité Spacelab. Ces deux systèmes sont dépendants de la Navette spatiale américaine dont le programme de lancement fait apparaître aujourd'hui en plus du vol Eureca déjà mentionné, quatre vols européens:

— la mission D2 du Spacelab en 1992

— le premier revol d'Eureca en 1993

— une mission Spacelab en 1994

— le deuxième revol d'Eureca en 1995.

Si de plus, une mission Spacelab était programmée en 1996, l'ensemble de ces vols constituerait une base capable d'assurer les objectifs définis ci-dessus avec un bon équilibre entre les expériences en environnement pressurisé et non pressurisé, entre les expériences automatiques et opérées par un astronaute, ce qui permet de satisfaire différentes communautés d'utilisateurs. Cependant, les vols suivant la mission D2 ne sont pas encore couverts budgétairement en Europe.

Le programme Columbus et l'ensemble des utilisateurs ont un intérêt commun évident pour ces vols préparatoires: les utilisateurs auront enfin un programme d'activités en vol qui assure la répétitivité des expériences et donc des résultats solides scientifiquement; le programme Columbus pourra ainsi:

— disposer d'un noyau d'utilisateurs au début des opérations;

— disposer d'une base de données scientifiques permettant d'orienter les activités en fonction de données objectives et d'étendre la communauté des utilisateurs à partir du noyau initial. En particulier, ces données scientifiques sont indispensables à tout investisseur qui voudrait calculer les risques pris en finançant tout ou partie d'une expérience spatiale;

— disposer, avec ces vols, d'une simulation réaliste des opérations Columbus et ainsi pouvoir valider les infrastructures et entraîner les équipes avant le début des opérations.

Finalement, le succès de Columbus sera mesuré par le nombre et la satisfaction de ses utilisateurs.

Les activités de promotion en cours

Les activités de promotion de Columbus n'en sont qu'à leur début puisque jusqu'ici priorité a été donnée au démarrage des activités relatives à la définition même de Columbus ainsi qu'à l'infrastructure au sol associée.

Certaines actions sont déjà en cours et elles prendront de l'ampleur quand le système Columbus sera définitivement spécifié et que les conditions d'accès seront définies, c'est-à-dire dès que le produit à promouvoir sera connu précisément.

Les moyens d'information en cours de développement

L'ESA a développé un certain nombre de prototypes qui sont en cours d'évaluation par les utilisateurs eux-mêmes et qui donneront naissance à des outils opérationnels après validation.

COPIDAB (Columbus Pictures Data Bank)
Cette banque de données images et video

est basée sur les archives de trois vols Spacelab auxquels l'ESA a participé en novembre 1983 (Spacelab-1), juillet 1985 (Spacelab-2) et novembre 1985 (Spacelab-D1).

Le système choisi reprend un logiciel du type hyper-media qui organise de manière simple et interactive les 200 photographies décrivant le système Spacelab et les expériences effectuées, ainsi que les sept cassettes video sur les résultats de certaines expériences réalisées en microgravité. L'information sélectionnée a été limitée aux expériences de Physique des Fluides et de Sciences de la Vie (Sled et Biorack) afin de permettre la réalisation rapide d'un prototype sur videodisque.

CUIS (Columbus Utilisation Information System)
Alors que COPIDAB s'adresse à un public non averti, CUIS est un outil développé dans le but d'offrir à la communauté des utilisateurs scientifiques et industriels de Columbus des services de communication, l'utilisation de simulateurs électroniques (téléscience, perturbations de l'environnement) ainsi que l'accès à diverses banques de données européennes et internationales (missions, équipements, charges utiles).

COPIDAB et CUIS se rejoindront lorsque les technologies de l'information permettront la diffusion et le stockage sur un même support numérique d'un texte, d'un graphique, d'une image et d'une video.

Ces systèmes ne remplacent pas les publications scientifiques mais permettent une organisation de l'information et une interaction avec l'information qui facilitent grandement l'accès aux données scientifiques.

COMADAB (Columbus Marketing Data Base)
COMADAB, créé autour d'une base de données d'adresses et de points de contact dans les milieux scientifiques et industriels non spatiaux, est un outil de marketing voué à identifier, classer et suivre les utilisateurs potentiels de Columbus.

Borne Interactive Columbus
Pour compléter l'approche des utilisateurs potentiels et s'adresser plus particulièrement aux utilisateurs de demain, une Borne Interactive Columbus est actuellement en projet. Elle constitue un outil d'éducation et de familiarisation à Columbus pour les étudiants à partir de 18 ans.

Le système est similaire à celui de COPIDAB et se complète d'une dimension pédagogique indispensable à la formation des nouveaux venus dans le 'Club Espace'.

La distribution de l'information

Le rôle de l''Organisation de Support aux Utilisateurs' (USO)
Sous la responsabilité de l'ESA, une équipe constituée de représentants de chaque Etat membre participant au programme Columbus travaille à la définition de l'organisation (infrastructure et personnel) chargée de fournir le support nécessaire aux utilisateurs pendant les opérations de Columbus.

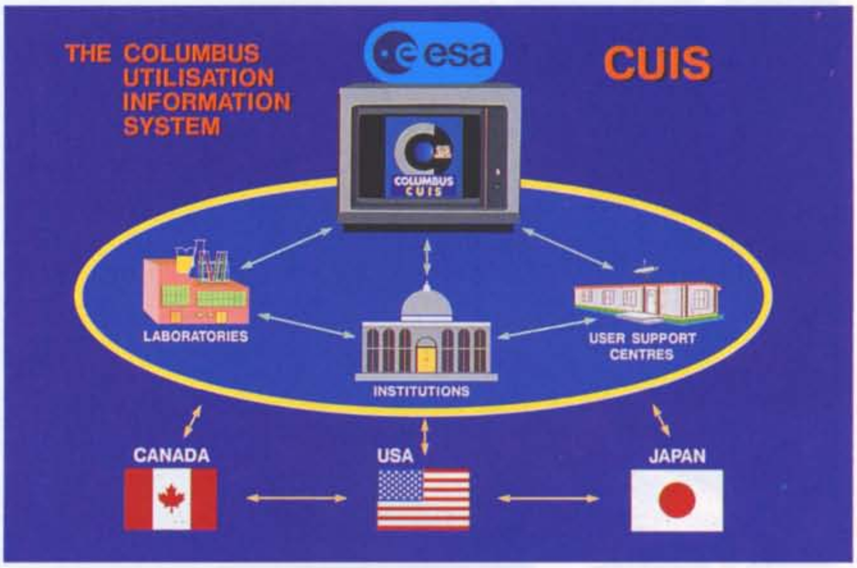


Figure 6. Le système CUIS (Columbus Utilisation Information System) relie laboratoires, organismes officiels et centres d'utilisateurs dans le monde

Cette équipe est formée de scientifiques et d'ingénieurs ayant tous l'expérience de l'utilisation de l'espace. Ils sont les représentants de leur communauté nationale dans l'organisation Columbus.

Ces représentants sont donc les mieux placés pour être les premiers ambassadeurs de Columbus dans leur communauté nationale. Ce rôle de promoteur de Columbus est essentiel; chaque représentant est informé des derniers développements du programme et se familiarise avec les outils de promotion disponibles, pour être à même de distribuer l'information dans son pays, en utilisant les circuits auxquels il appartient et les forums auxquels il participe.

Les rendez-vous Columbus
En plus des nombreuses réunions, symposiums, ateliers de travail auxquels les représentants du programme Columbus participent, qu'ils soient de l'ESA ou d'Agences nationales, le programme

Columbus organise directement des rendez-vous avec les utilisateurs potentiels.

Le Symposium Columbus se tient chaque année alternativement en Allemagne et en Italie, pays co-organisateurs, et rassemble les représentants du programme, l'industrie spatiale et les utilisateurs potentiels.

Plus orienté vers la commercialisation, le rendez-vous de Montreux, 'Space Commerce', est bi-annuel et rassemble les représentants des quatre partenaires de la Station spatiale et les utilisateurs potentiels, essentiellement du domaine industriel.

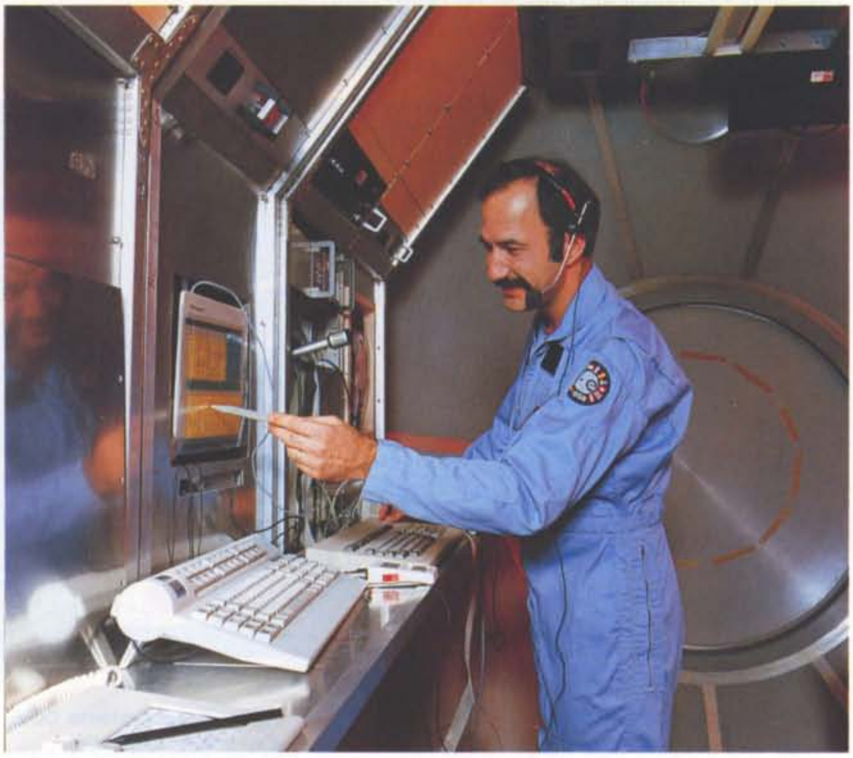


Figure 7. Wubbo Ockels teste le crayon optique qui sera utilisé dans le Laboratoire attaché

Les études de promotion

En liaison avec le bureau de commercialisation de l'ESA, le programme Columbus finance quelques études de promotion du programme.

Les objectifs de ces études sont les suivants:
- identification des utilisateurs potentiels de Columbus; revue de l'état actuel et des tendances des recherches et des applications pouvant bénéficier de l'environnement spatial;
- identification des difficultés et obstacles auxquels les utilisateurs sont aujourd'hui confrontés quand ils veulent utiliser l'environnement spatial, y compris les problèmes de financement et les aspects légaux;
- définition des mesures à prendre pour améliorer la situation et répondre au mieux aux besoins identifiés;
- définition d'une politique de promotion adaptée à chaque domaine d'intérêt;
- définition du rôle de chacun dans l'application de cette politique.

Les activités préparatoires

Les activités préparatoires sont multiples et ne sont pas du seul ressort du programme Columbus. En particulier, les activités à caractère scientifique sont de la responsabilité des programmes d'utilisation. Cependant, le programme Columbus s'attache à fournir à la communauté des utilisateurs:
- des simulateurs et des bancs d'essais au sol leur permettant de se familiariser dès maintenant avec le système Columbus et les opérations associées;
- des opportunités de vol suivant l'objectif décrit plus haut, basées sur l'utilisation de la plate-forme Eureca et du laboratoire Spacelab, sans négliger les capacités offertes par d'autres systèmes comme les fusées-sondes.

En ce qui concerne les simulateurs, le programme Columbus a installé, à l'ESTEC, une maquette à échelle 1 du Laboratoire attaché qui sert à l'étude des interfaces des charges utiles, de leur installation dans le Laboratoire et des interfaces opérationnels avec l'astronaute. Un banc d'essais 'téléscience' permet à tout utilisateur de simuler les opérations de son expérience placée à bord de la maquette ci-dessus, à partir d'une console standard placée dans une salle à distance. Un banc d'essais 'robotique' permettra à tout utilisateur de se familiariser avec les possibilités d'opérations de sa charge utile offertes par un robot.

En ce qui concerne les opportunités de vol, le programme Columbus, en liaison avec les programmes d'utilisation, cherche à définir la mission et le financement de deux nouveaux vols d'Eureca et de deux vols du Spacelab.

De plus, un accord de coopération est en cours de discussion avec la NASA sur l'ensemble des vols préparatoires à l'utilisation de la Station spatiale puisque la NASA définit de son côté un programme de vols préparatoires. Cette coopération permettrait de rôder les mécanismes qui seront mis en place pour gérer les missions de la Station spatiale où cohabiteront, tant pour l'utilisation que pour les opérations, quatre partenaires: Etats-Unis, Japon, Canada et Europe.

Förderung der Columbus-Nutzung*

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Columbus läutet eine neue Ära der Weltraumnutzung ein wegen seiner Größe, wegen Anzahl und Vielfalt seiner Ressourcen, wegen seiner ständigen Anwesenheit im Orbit und wegen der Zahl seiner potentiellen Nutzer.

Columbus bietet daher jedermann eine einmalige Chance — 'Stammkunden' des Weltraums mit einer Kontinuität der Leistungen, ohne die es weder Erkenntnisse noch Anwendungen gibt, aber auch neuen Interessenten aus Bereichen, für die der Nutzen der Weltraumumgebung noch nicht erwiesen ist. Für letztere orientiert und verstärkt Columbus das Bedürfnis nachzuweisen, daß die Weltraumnutzung für die betreffenden Bereiche von Interesse ist (oder auch nicht), durch die Vorgabe eines wichtigen Datums: Beginn der Columbus-Operationen, bis zu dem diese Bereiche eindeutig identifiziert worden sein müssen.

Diese Chance kann jedoch nur wahrgenommen werden, wenn bis zur Indienststellung von Columbus alle potentiellen Nutzer angesprochen, unterrichtet und vorbereitet werden. Und das soll mit der Förderung der Columbus-Nutzung erreicht werden.

Das Columbus-Programm und seine Nutzung

Columbus ist der Beitrag der Europäischen Weltraumorganisation (ESA) zum US-Projekt Freedom-Raumstation. Letztere soll eine bemannte Basis aus den USA sowie von Europa, Japan und Kanada gelieferte Elemente umfassen und wird ab 1995 in der Umlaufbahn zusammengebaut.

Hauptzweck des Columbus-Programms ist es, europäischen und anderen Nutzern eine Weltraum- und Bodeninfrastruktur zur Verfügung zu stellen, die deren künftigen Bedürfnissen gerecht zu werden vermag. Ferner wird dieses Programm Europa die erfolgreiche Durchführung einer fruchtbaren Zusammenarbeit mit seinen internationalen Partnern ermöglichen und gleichzeitig einen ersten Schritt auf dem Weg zu europäischer Eigenständigkeit im bemannten Raumflug darstellen.

Das Columbus-Programm beinhaltet folgende drei Elemente:

- Columbus Attached Laboratory, ein permanent an die Freedom-Raumstation angekoppeltes, druckgeregeltes Modul mit vier Segmenten vom Spacelab-Typ.
- Columbus Free Flying Laboratory, das mit der Freedom-Raumstation gemeinsam kreist, während sechs Monaten automatisch arbeitet und zweimal jährlich vom Raumtransporter Hermes oder durch die Freedom-Raumstation versorgt wird.
- Polare Plattform mit automatischer Funktionsweise, die hauptsächlich für Erdbeobachtungsinstrumente gedacht ist.

Diese drei Elemente schaffen ein gutes Gleichgewicht zwischen unbemannten und bemannten Einrichtungen und können daher den unterschiedlichsten Bedürfnissen der Nutzer Rechnung tragen.

Von Anbeginn ging das Columbus-Programm über die reinen Nutzungsbedürfnisse hinaus. Es verfolgt auch Ziele in Politik (Gleichgewicht zwischen westlicher Kooperation und europäischer Eigenständigkeit), Strategie (Verfügung über Technologie und Werkzeuge der Zukunft) und Industrie (Bestätigung und Stärkung der Errungenschaften der europäischen Raumfahrtindustrie nach dem Erfolg der Programme Ariane und Spacelab).

Endziel ist jedoch, diese ganze Infrastruktur zu nutzen und bestmöglich zu vermarkten, also Nutzer anzulocken und zufriedenzustellen.

Eine Raumstation läßt sich auf sehr unterschiedliche Weise nutzen — als Transportetappe für Fernmissionen, zum Zusammenbau von Großstrukturen, zur Wartung erdnah kreisender Satelliten oder auch als Labor für wissenschaftliche Experimente, technologische Tests und die Entwicklung von Herstellungsverfahren. Eine

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* In French on page 25.

bevorzugte Columbus-Nutzung von vornherein gibt es zwar nicht, doch sollen zumindest in der Anfangsphase Laboraktivitäten inner- oder außerhalb der druckgeregelten Zone mit Instrumenten Vorrang genießen, die an die Infrastruktur gekoppelt oder unabhängig, aber koorbital sind und von der Raumstation gesteuert werden.

Ungeachtet der Art von Versuchen oder Instrumenten ergibt sich der entscheidende Wert einer Raumstation daraus, daß Transporte von Infrastrukturelementen für jede einzelne Nutzung der Weltraumumgebung entfallen. Die Infrastruktur verbleibt vielmehr in der Umlaufbahn, und die Transporte beschränken sich auf Nutzlasten. Da die Kosten für Aktivitäten im Weltraum zur Hälfte transportabhängig sind, bedeutet dies erhebliche Einsparungen. (Zur Veranschaulichung: Das bemannte Spacelab hat eine Startmasse von 14 Tonnen, aber nur zwei Tonnen Nutzlast, und bei der automatischen Plattform Eureca lautet das entsprechende Verhältnis 4,5:1).

Trotz dieser Gegebenheiten ist die Förderung der Columbus-Nutzung nicht einfach,

— weil zeitplanbedingt Columbus erst in acht Jahren einsatzbereit sein wird, und es schwierig ist, derzeitige Nutzer so langfristig zu interessieren;
— weil Columbus eine so hohe Lebenserwartung (30 Jahre) hat, daß sich mehrere Nutzergenerationen mit unterschiedlichen Bedürfnissen ablösen werden;
— weil die Kapazitäten von Columbus — und der Raumstation ganz allgemein — so groß sind, daß es zu jedem Zeitpunkt Hunderte von Nutzern geben wird, die recht unterschiedliche Ziele verfolgen.

Da also die Zielgruppen nicht hinreichend bekannt sind, läßt sich eine Förderungsstrategie nur schwer definieren.

Aus diesem Grund wird die Förderung allein nicht genügen, um den Erfolg der Columbus-Nutzung sicherzustellen. Es muß vielmehr ein *hinreichend flexibles* Columbus-Systems entwickelt werden, damit unterschiedliche und sich wandelnde Bedürfnisse seitens der Nutzer berücksichtigt werden können.

Damit ist der Begriff 'Labor' angesprochen, wie er auf der Erde besteht. Ein Labor bietet Platz zum Aufstellen von Instrumenten sowie Hilfsmittel (Rechner, Strom, Techniker usw.) für deren Betrieb und Bedienung. Welche Instrumente und Experimente das sind, hängt von den jeweiligen Laborbenutzern ab. Neben den Hilfsmitteln für die Benutzer kann ein Labor auch ein besonderes Umfeld bieten wie beispielsweise in der Antarktis, unter Wasser und natürlich im Weltraum. Letzterer ist durch drei einzigartige Besonderheiten gekennzeichnet: Große Höhe, Vakuum unendlichen Ausmaßes und Langzeit-Mikrogravitation.

Um unterschiedliche und noch nicht eindeutig erkannte Bedürfnisse zu befriedigen, muß ein Labor anpassungsfähig sein. Bei einem Weltraumlabor bedeutet dies Tauglichkeit für Konfigurationsänderungen und eine gewisse Autonomie für die Nutzer. Erreicht wird dies durch dezentrale Operationen und die Dialogmöglichkeit zwischen dem Nutzer auf der Erde und seinem Instrument in der Umlaufbahn (Konzept der 'Fernforschung'). Ein leistungsfähiges Labor muß Nutzungshilfen bereitstellen, die auf das Aufnahmevolumen für Experimente abgestimmt sind. Namentlich die Kapazitäten zur Bedienung der Bordinstrumente (durch Astronauten, Roboter, Automatik) müssen deren Anzahl und Typ entsprechen. Die besten Ergebnisse zeitigt das Umfeld eines Labors mit Einrichtungen für die quantitative Messung dieses Umfeldes. Bekannt sein müssen insbesondere Grad und Richtung der Mikrogravitation am Ort jedes einzelnen Experimentes.

Es muß daher ein Columbus-System entwickelt werden *mit leichtem Zugang für alle Nutzer* — von einzelnen Wissenschaftlern bis zur Großindustrie.

Leichter Zugang bezieht sich auf zahlreiche Aspekte, von denen die wichtigsten nachstehend aufgeführt sind:

— Für europäische Nutzer Zugang zu allen Möglichkeiten, die sowohl Columbus wie die Freedom-Raumstation bieten. Die Übereinkunft (MoU) über die Raumstation beschränkt den Zugang für die Europäer auf Columbus (also auf einen druckgeregelten Bereich mit alleiniger Öffnung zum Weltraum über die Experimenteschleuse für kleine Instrumente), gestattet allerdings die Benutzung der äußeren Anhängepunkte für Instrumente im Tausch oder gegen Entgelt. Da der Zugang nach außen wichtig ist, müssen sämtliche Voraussetzungen geschaffen werden, um ihn regelmäßig wahrzunehmen gegen die Nutzung eines Teils des Columbus Free

Flying Laboratory oder gegen europäische Ausrüstungslieferungen (Ausrichtsystem, System zur Umweltmessung).

- Rasche Einplanung der Experimente, damit Nachfrage und Bedürfnisse der Nutzer möglichst schnell berücksichtigt werden können.
- Hohe Systemverfügbarkeit, um die Zeiten für den Zugang sowie für die Rückkehr der Experimente und ihrer Resultate zu verkürzen. Kontinuierlicher Service und häufiger Verkehr zwischen der Erde und Columbus sind von entscheidender Bedeutung für das Interesse an der Raumstation.
- Nutzerunterstützung bei der Vorbereitung von Instrumenten und Experimenten am Boden und während der Operationen im Flug. Diese Unterstützung ist von speziellen Zentren zu leisten, deren Fachleute den Nutzern die Lösung der Probleme in Verbindung mit der Weltraumumgebung abnehmen, damit die Nutzer sich auf die wissenschaftlichen und technischen Aspekte ihrer Experimente konzentrieren können. Unterstützung dieser Art ist um so wichtiger, als die Columbus-Nutzergemeinde den Rahmen der traditionellen Weltraumnutzer sprengen wird.
- Attraktive Preispolitik im Verein mit einem eindeutigen Auswahlmodus für Experimente. Nutzer, die einen Teil oder die Gesamtheit der Kosten für ein Weltraumexperiment bezahlen, müssen genau wissen, was sie kaufen, und welche Rechte und Pflichten die verschiedenen, ihnen angebotenen Kostenbeteiligungssätze beinhalten. Grundlagenforscher erhalten weitgehende finanzielle Unterstützung, werden allerdings allein nach dem wissenschaftlichen Wert der von ihnen vorgeschlagenen Experimente ausgewählt und müssen deren Ergebnisse veröffentlichen. Industriellen Nutzern hingegen wird ein Großteil der operationellen Kosten berechnet, wenn sie die wissenschaftliche Auswahl umgehen und die Ergebnisse für sich behalten wollen.
- Gesetzliche Regelungen unter Berücksichtigung der besonderen Gegebenheiten einer internationalen Raumstation, in der möglicherweise ein europäisches Experiment von einem US-Astronauten in einem japanischen Labor durchgeführt wird. Der Schutz von Knowhow und Ergebnissen muß sichergestellt sein, und die Patentpolitik hat die Interessen aller Betroffenen zu wahren.

Mit all diesen Zielsetzungen beschäftigen sich die zuständigen Stellen im Rahmen der Vorbereitung der Columbus-Nutzung.

Sind sie erreicht, muß die Förderung der Columbus-Nutzung den Aufbau einer Gemeinde von Nutzern gestatten, indem diese davon überzeugt werden, daß ihre Bedürfnisse bei der Freedom-Raumstation in besten Händen sind.

Die Förderung der Columbus-Nutzung

Die Förderung der Columbus-Nutzung erfolgt auf zwei ebenso unverzichtbaren wie sich ergänzenden Ebenen:

- Information für die und von der Gesamtheit der potentiellen Nutzer.
- Vorbereitende Aktivitäten mit dem Ziel, möglichst frühzeitig die Beziehungen zwischen Nutzern und Columbus auf eine konkrete Basis zu stellen.

Förderung durch Information

Welche Information?

Die Unterrichtung potentieller Nutzer ist entscheidend, weil diese allein dadurch das System in der Umlaufbahn und die von ihm gebotenen Vorteile kennenlernen können.

Sie erfolgt in mehreren Abstufungen unter ganz allgemeinen bis zu hochwissenschaftlichen Aspekten:

- Der Weltraum und die Merkmale dieses Umfeldes.
- Columbus-System, Raumstation, vorhandene Ressourcen und Zugangsbedingungen.
- Wissenschaftliche und technologische Bereiche, die aus der Weltraumumgebung Nutzen ziehen können.
- Datenbank mit den Ergebnissen von Experimenten, aufgeschlüsselt nach wissenschaftlichen Bereichen.

Dieser wissenschaftlichen Datenbank kommt besondere Bedeutung zu, weil sie den objektiven und konkreten Beweis für den Nutzen der Weltraumumgebung liefert. Einschlägige Daten sind noch selten und überdies verstreut. Es besteht daher ein echtes Bedürfnis, sie auf internationaler Ebene zu sammeln. Eine Koordination zwischen allen betroffenen Stellen ist angelaufen und dürfte die gegenwärtige Situation verbessern.

Welche Informationsmittel?

Zum Einsatz gelangen klassische, nicht weltraumspezifische Mittel von Tagungen und Seminaren mit direktem Gedanken-austausch zwischen 'Anbietern' und 'Abnehmern' bis zu elektronischen Systemen mit umfangreichen Informationskapazitäten, die vielfachen Austausch und Dialog zwischen den Nutzern gestatten. Aber auch Dokumente haben hier noch ihren Platz als erste Informationsmaßnahme oder als Unterlagen für den Gedankenaustausch auf Tagungen.

Neben diesen eher immateriellen Mitteln werden Präsentation von Fluggerät — namentlich Nutzlasten mit ihren Schnittstellen — und Zugang zu Funktionssimulatoren — namentlich für die Bord-Datenverwaltung — potentielle Nutzer in den Stand versetzen, sich mit dem System in der Umlaufbahn, mit seinen Schnittstellen und mit den vorhandenen Kapazitäten unmittelbar vertraut zu machen. Dank einer solchen aktiven und konkreten Beteiligung bereits in diesem Stadium können künftige Nutzer sehr früh in die verschiedenen Etappen der Missionsvorbereitung einbezogen werden.

Die Informationsmittel sind möglichst dezentral einzusetzen, damit der Weg zu allen potentiellen Nutzern möglichst kurz ist und vermieden wird, daß deren erste Annäherung an Columbus zu große Entfernungen überwinden muß.

Information für wen?
Wenn man davon ausgeht, daß
— der Zeitraum der operativen Columbus-Nutzung sich von 1997 bis 2027 erstreckt;
— Columbus Kapazitäten anbietet, die um das Zehn- bis Hundertfache über den Kapazitäten bestehender Weltraum-Infrastrukturen liegen;
— und daß es bisher keine organisierte Nutzergemeinde gibt,
dann darf von vornherein kein einziger potentieller Nutzer übergangen werden.

Die Columbus-Förderung muß sich also an sämtliche Bereiche richten — von der Grundlagen- bis zur Anwendungsforschung, von der Schwerelosigkeitsnutzung bis zur Astrophysik, von der Raumfahrt bis zu traditionellen Industriezweigen.

Um die Bemühungen aber nicht zu stark zu verzetteln und voreilige Maßnahmen zu vermeiden, die sich als abträglich erweisen könnten, sind die Förderungsaktivitäten in Etappen zu organisieren, um die verschiedenen potentiellen Nutzer in logischer Abfolge ansprechen zu können.

Für Bereiche, in denen die Vorteile der Weltraumnutzung schon eindeutig nachgewiesen sind (Weltraum- und Erdbeobachtung), und für Tests zur Validierung von Weltraumtechnologien (Antennenentfaltung, Versuche mit Umweltsensoren usw.) besteht die Förderung darin, Interessenten aufzuzeigen, aus welchem der nachstehenden Gründe Columbus und die Freedom-Raumstation gegenüber einem anderen Träger vorzuziehen sind:
a) Verfügbarkeit mit kurzen Fristen zwischen Flugentscheidung und Flug.
b) Geringere Kosten wegen bereits vorhandener Infrastruktur.
c) Aufnahmevermögen für große Instrumente oder für mehrere Instrumente nebeneinander.
d) Ständige Anwesenheit von Astronauten.

Wo die Vorteile der Weltraumnutzung noch nicht endgültig feststehen, ist eine Demonstrationsphase erforderlich, während der Experimente und schlüssige Ergebnisse aneinandergereiht und wiederholt werden müssen. Dies trifft zu auf Mikrogravitation und Vakuum (bei letzterem unter Einschluß der 'Solar'-Anwendungen). Die Demonstrationsphase hat bereits begonnen, wird aber mindestens bis in die Anfangsphase der Columbus-Operationen hineinreichen. Sie bezieht sich vor allem auf die Grundlagenforschung, weswegen sich die Förderung in erster Linie auf die Wissenschaft unter besonderer Berücksichtigung des studentischen Nachwuchses und auf die Forschungsabteilungen der Industrie konzentrieren muß. Die Gewinnung der Wissenschaft ist wichtig als Voraussetzung dafür, daß Fortschritte in der wissenschaftlichen Erkenntnis erzielt und anerkannt werden. Ebenfalls nützlich ist die Einbeziehung der Industrie in die Demonstrationsphase, damit sie nicht nur über wissenschaftliche Entwicklungen unterrichtet wird, sondern auch Forschungsschwerpunkte entsprechend ihren Bedürfnissen setzen kann.

Information durch wen?
Columbus-Förderung ist eine Aufgabe für alle — für die ESA ebenso wie für nationale Raumfahrtbehörden und Sondergremien wie Intospace und Novespace und vor allem natürlich für die Nutzer, die schon mit vorbereitenden Aktivitäten beschäftigt sind. Neue Nutzer werden nämlich in erster Linie durch die Zufriedenheit derzeitiger Nutzer angelockt.

Damit kein potentieller Nutzer vom Informationsfluß abgeschnitten bleibt, muß die Verbreitung der Informationen dezentralisiert werden. Der ESA und nationalen Raumfahrtbehörden obliegt es, Informationen zusammenzustellen und Informationsinstrumente zu entwickeln. Nationalen Stellen aus dem öffentlichen und privaten Sektor hingegen fällt die Aufgabe zu, die Informationen in ihren Ländern über vorhandene Kanäle (z.B. wissenschaftliche Gesellschaften oder Fachverbände) zu verbreiten. Und da Aussagen derzeitiger Nutzer entscheidendes Gewicht haben, müssen ESA und nationale Raumfahrtbehörden sie auf diese Informationsaktivität vorbereiten und dabei unterstützen.

Förderung durch vorbereitende Aktivitäten
Wissenschaftler, Forscher, Ingenieure oder Studenten werden nur Nutzer, wenn sie Gelegenheit zu Experimenten erhalten. Der einzige Weg zur Schaffung eines Kerns von Nutzern vor der Einsatzbereitschaft von Columbus führt daher über das Angebot von Gelegenheiten zur Durchführung von Experimenten am Boden und in der Umlaufbahn.

Aktivitäten am Boden und in der Umlaufbahn sind beide nötig und ergänzen sich. Erstere — einschließlich Versuchen im Freifallturm und auf Parabelflügen — gestatten die Vorbereitung der Instrumente und Experimente, die später in die Umlaufbahn gebracht werden; dank letzterer können die weltraumspezifische Umgebung genutzt und deren Vorteile auf den Gebieten aufgezeigt werden, für die ein solcher Nachweis noch erforderlich ist.

Bodenaktivitäten umfassen wissenschaftliche Forschungen im Zusammenhang mit Experimenten, technologische Untersuchungen im Zusammenhang mit der Instrumentierung und operationsrelevante Vorhaben wie Ferndialog zwischen Nutzer und Experiment (Konzept der 'Fernforschung').

Weltraumaktivitäten sind das Endziel aller Vorbereitungen. Trotz ihrer geringer Zahl bis zum Beginn des Columbus-Einsatzes spielen sie eine entscheidende Rolle für:
- den Aufbau und die Stärkung eines ersten Kerns von Columbus-Nutzern;
- die Gewinnung wissenschaftlich tragfähiger Ergebnisse aus Experimenten in noch nicht anerkannten Bereichen wie der Nutzung der Mikrogravitation;
- ein besseres Verständnis des Freedom-Konzeptes und eine Verkürzung der zeitlichen Perspektive durch den Start von Experimenten des Columbus-Typs vor 1997 (also schon jetzt Interesse wecken für die Columbus-Nutzung);
- die Schaffung von Ereignissen, die das Interesse nicht nur der Nutzer, sondern auch von Entscheidungsträgern und Öffentlichkeit wachhalten.

Aus all diesen Gründen müssen die vorbereitenden Columbus-Flüge als ein Ganzes programmiert werden, das für die Aktivitäten im Weltraum Kontinuität und Wiederholbarkeit garantiert. Die Gewißheit der Kontinuität ist nämlich alleinige Gewähr für eine echte wissenschaftliche Strategie und für Kohärenz auf dem Weg zur Columbus-Nutzung.

Zur Programmierung der Vorbereitungsflüge für Europa verfügbar ist derzeit eine orbitale Infrastruktur mit der automatischen Plattform Eureca, deren Erstflug 1991 stattfinden wird, und dem bemannten Weltraumlabor Spacelab. Beide Systeme sind von dem amerikanischen Space Shuttle abhängig, in dessen Startkalender gegenwärtig — neben dem vorgenannten Eureca-Start — folgende vier europäischen Buchungen stehen:
- Spacelab-Mission D2 1992
- Erster Eureca-Wiederholungsflug 1993
- Eine Spacelab-Mission 1994
- Zweiter Eureca-Wiederholungsflug 1995

Wenn außerdem eine Spacelab-Mission für 1996 angesetzt wird, ergäbe die Gesamtheit dieser Flüge eine akzeptable Grundlage für die Erreichung der vorgenannten Ziele mit einem guten Gleichgewicht zwischen Experimenten in einer Umgebung mit und ohne Druckregelung sowie zwischen Experimenten mit und ohne Betreuung durch Astronauten, so daß die verschiedensten Nutzergruppen zufriedengestellt werden könnten. Die Flüge nach Mission D2 sind allerdings in Europa budgetmäßig noch nicht abgedeckt.

Die vorbereitenden Flüge sind eindeutig von gemeinsamem Interesse für das Columbus-Programm und sämtliche Nutzer. Für letztere gibt es endlich ein Programm mit Flugaktivitäten, das die Wiederholbarkeit von Experimenten und damit wissenschaftlich tragfähige Resultate gewährleistet, und das Columbus-Programm erhielte auf diese Weise:
- einen Kern von Nutzern zu Betriebsbeginn;
- eine wissenschaftliche Datenbank zur Orientierung der Aktivitäten an objektiven Daten und zur Erweiterung der Nutzergemeinde; die wissenschaftlichen Daten sind insbesondere für jeden Interessenten unverzichtbar, der die Risiken bei der Gesamt- oder Teil-

finanzierung eines Weltraumexperimentes kalkulieren möchte;
- eine realistische Simulation der Columbus-Operationen, um die Infrastrukturen zu validieren und die einzelnen Teams bereits vor Beginn der Operationen zu interessieren.

Der Erfolg von Columbus wird letztendlich an Zahl und Zufriedenheit seiner Nutzer gemessen werden.

Die laufenden Förderungsmaßnahmen

Eigentliche Förderungsmaßnahmen wurden noch kaum ergriffen, da bisher die Arbeiten zur Columbus-Definition und an der zugehörigen Bodeninfrastruktur Vorrang genossen haben.

Bestimmte Aktionen, die bereits angelaufen sind, sollen ausgebaut werden, sobald das Columbus-System endgültig festgeschrieben ist und die Zugangsbedingungen definiert sind (also sobald das zu fördernde Produkt genau bekannt ist).

Informationsmittel in der Entwicklung

Die ESA hat einige Prototypen entwickelt, die derzeit von Nutzern bewertet werden, und aus denen nach der Validierung funktionsfähige Werkzeuge geschaffen werden sollen.

— COPIDAB (Columbus Pictures Data Bank)
Diese Bild- und Videodatenbank stützt sich auf die Archive der drei Spacelab-Flüge mit ESA-Beteiligung im November 1983 sowie im Juli und November 1985 (Spacelab-1, -2 bzw. D1).

In das gewählte System wurde eine Hypermedia-Software übernommen, welche die 200 Fotos mit Beschreibung des Spacelab-Systems und der durchgeführten Experimente sowie die sieben Videokassetten mit den Resultaten bestimmter Experimente unter Mikrogravitation auf einfache und interaktive Weise organisiert. Die ausgewählten Informationen beschränken sich auf fluidphysikalische und biowissenschaftliche Experimente (SLED und Biorack), damit rasch ein Prototyp auf Bildplatte verwirklicht werden konnte.

— CUIS (Columbus Utilisation Information System)
Während COPIDAB für ein Laienpublikum bestimmt ist, wurde CUIS entwickelt, um der Columbus-Nutzergemeinde aus Wissenschaft und Industrie Kommunikationsdienste und die Nutzung elektronischer Simulatoren ('Fernforschung', Umweltstörungen) zu erschließen sowie den Zugriff auf verschiedene europäische und andere Datenbanken (Missionen, Ausrüstungen, Nutzlasten) zu ermöglichen.

COPIDAB und CUIS werden zusammengeführt, sobald informationstechnisch die Möglichkeit besteht, Texte, Graphiken, Bilder und Videos auf dem gleichen numerischen Träger zu speichern und zu verbreiten.

Diese Systeme sind kein Ersatz für wissenschaftliche Publikationen, sondern gestatten eine Organisation der Informationen und eine Interaktion mit denselben, die den Zugang zu wissenschaftlichen Daten erheblich erleichtern.

— COMADAB (Columbus Marketing Data Base)
COMADAB gründet auf einer Datenbank mit Adressen und Kontakten in der raumfahrtfremden Wissenschaft und Industrie und soll als Marketinginstrument potentielle Columbus-Nutzer identifizieren, klassifizieren und nachfassend bearbeiten.

— Columbus-Teleseminar
Zur Ergänzung der Ansprechmittel für potentielle Nutzer und speziell zum Ansprechen der Nutzer von morgen wird derzeit an dem Projekt 'Teleseminar' gearbeitet. Dieses Instrument soll Studenten ab 18 Jahren über Columbus unterrichten und damit vertraut machen.

Das System ähnelt COPIDAB, hat aber darüber hinaus eine pädagogische Dimension, die für die Ausbildung von neuen Mitgliedern im 'Weltraum-Club' unerläßlich ist.

Informationsverbreitung

— Die Rolle der 'Nutzerunterstützungsorganisation' (USO)
Unter den Fittichen der ESA definiert eine Gruppe von Vertretern aus allen am Columbus-Programm teilnehmenden Mitgliedstaaten die Organisation (Infrastruktur und Personal), die den Nutzern während der Columbus-Operationen die erforderliche Unterstützung angedeihen lassen soll.

Die Gruppe besteht aus Wissenschaftlern und Ingenieuren mit Erfahrungen in der Weltraumnutzung, die ihre nationalen Verbände in der Columbus-Organisation repräsentieren.

Sie eignen sich daher bestens als Columbus-Botschafter in ihrem jeweiligen Heimatland. Diese Fördererrolle ist entscheidend, denn jeder einzelne wird über die jüngsten Entwicklungen des Programms unterrichtet und macht sich mit den vorhandenen Förderungsinstrumenten vertraut. So können sie die Informationen in ihrem Land über die Kanäle und Veranstaltungen verbreiten, zu/an denen sie Zugang haben beziehungsweise teilnehmen.

— *Columbus-Treffen*
Abgesehen von den zahlreichen Tagungen, Symposien und Workshops, an denen Vertreter des Columbus-Programms aus ESA oder nationalen Raumfahrtbehörden teilnehmen, werden in dessen Rahmen auch Treffen mit potentiellen Nutzern veranstaltet.

Das Columbus-Symposium findet jährlich abwechselnd in den beiden Veranstalterländern BRD und Italien statt und vereint Programmrepräsentanten, Raumfahrtindustrie sowie potentielle Nutzer.

Auf der stärker kommerziell orientierten Veranstaltung 'Space Commerce', die alle zwei Jahre in Montreux/Schweiz stattfindet, treffen sich Vertreter der vier Freedom-Partner mit potentiellen Nutzern namentlich aus der Industrie.

Förderungsstudien
In Verbindung mit dem ESA-Vertriebsbüro werden über das Columbus-Programm einige Förderungsstudien finanziert.

Mit diesen Studien werden folgende Ziele angepeilt:
- Identifizierung potentieller Columbus-Nutzer; Überblick über aktuellen Stand und Tendenzen von Forschungen und Anwendungen, welche die Weltraumumgebung fördern könnte.
- Identifizierung aktueller Schwierigkeiten und Hindernisse für potentielle Nutzer der Weltraumumgebung (u.a. Probleme der Finanzierung und juristische Aspekte).
- Definition von Maßnahmen zur Verbesserung der Situation und zur besseren Abdeckung der erkannten Bedürfnisse.
- Definition einer Förderungspolitik mit spezifischer Abstimmung auf jedes einzelne Interessengebiet.
- Definition der Rolle jedes einzelnen in der Durchführung dieser Politik.

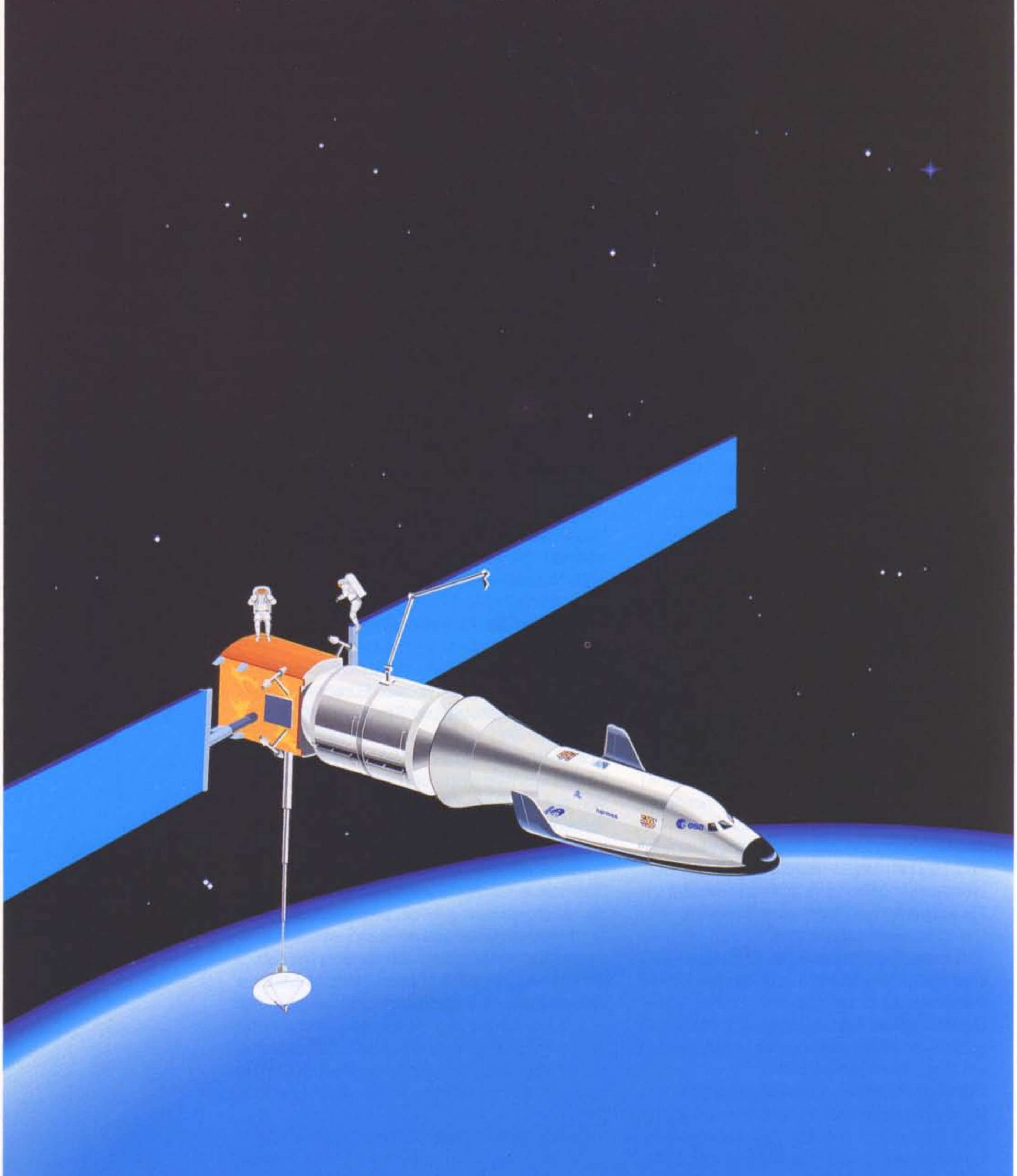
Vorbereitungen
Die vorbereitenden Aktivitäten sind vielfältig und liegen teilweise außerhalb des Columbus-Programms. Namentlich die wissenschaftlichen Aktivitäten fallen in die Zuständigkeit der Nutzungsprogramme. Dennoch bemüht sich das Columbus-Programm für die Nutzergemeinde um:
- Bereitstellung von Simulatoren und Prüfständen am Boden, damit sich die Nutzer schon jetzt mit dem Columbus-System und den einschlägigen Operationen vertraut machen können;
- Angebot von (Mit)fluggelegenheiten - wie oben erläutert - auf der Grundlage der Nutzung von Eureca-Plattform und Spacelab, ohne die Kapazitäten anderer Systeme wie Höhenraketen außer Acht zu lassen.

Für Simulationen wurde im Europäischen Raumfahrt- und Technologiezentrum ESTEC eine Columbus Attached Laboratory-Nachbildung im Maßstab 1:1 erstellt, die dazu dient, Nutzlasten-Schnittstellen und ihre Einrichtung im Attached Laboratory sowie die Schnittstellen für Bedienung durch Astronauten zu studieren. Dank eines Prüfstandes 'Fernforschung' kann jeder Nutzer die Operationen seines Experimentes an Bord der Attached Laboratory-Nachbildung von einer Standardkonsole simulieren, die in einem anderen Raum steht. Und an einem Robotik-Prüfstand können Nutzer sich mit den Möglichkeiten vertraut machen, die ein Roboter für die Manipulation ihrer Nutzlasten bietet.

Hinsichtlich der Fluggelegenheiten bemüht man sich in Verbindung mit den Nutzungsprogrammen um Missionsdefinition und Finanzierung für je zwei Eureca-Wiederholungsflüge und Spacelab-Flüge.

Überdies wird mit der NASA über eine Kooperationsvereinbarung verhandelt, die sich auf die Gesamtheit der Flüge zur Vorbereitung der Freedom-Nutzung bezieht, da nämlich die NASA ebenfalls ein Programm vorbereitender Flüge definiert. Dank einer solchen Kooperation könnten sich die Mechanismen zur Führung der Missionen der Freedom-Raumstation einspielen, in der sowohl für die Nutzung wie für den Betrieb die vier Partner USA, Japan, Kanada und Europa zusammengespannt sind.

Figure 1. The Hermes European spaceplane, its robotic arm system (HERA), and astronaut EVA



External Servicing of Spacecraft — The Hermes Capability

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With the commitment of all of the major space powers to the development and operation of permanent space-based infrastructures, the need for servicing, maintenance, and upgrading of those infrastructures in orbit is clear. The general thrust of the design of such Space Stations is to maximise the availability of crew members for performing such servicing in a 'shirt-sleeve' environment, and therefore to locate as much equipment as possible within the habitable volume. However, for reasons such as safety, volumetric efficiency and functionality, a number of items must be located outside the pressurised volume. These items have also to be serviceable in some way, and therefore the permanent infrastructure itself or its servicing vehicle(s) must be able to undertake that external servicing.

In the context of ESA's manned space programme, one of the Hermes system's primary tasks will be the servicing of the Columbus Free-Flying Laboratory. Coupled with the parallel objective of developing capabilities and technologies to satisfy the desire for European autonomy in space, this has led to the requirement for Hermes to include external servicing capabilities. Such external intervention can be effected by the crew themselves (so-called 'Extra-Vehicular Activity', or 'EVA'), by using tele-operated robotics, by a combination of the two, or by completely automated means. This article focuses on the first three of these options, which are being developed as part of the Hermes system, and concentrates specifically on the EVA suit systems and the Hermes Robot Arm, or 'HERA' (Fig. 1).

Experience to date outside Europe

EVA was the initial method of external intervention in space developed for both the American and Russian programmes. Now both of those programmes have also developed robotic capabilities, relying on the Space Shuttle's Canadian-provided Remote Manipulator System (RMS), and the MIR Robot Arm, respectively. Both countries have used astronaut EVA in the past for significant recovery tasks involving damaged spacecraft — NASA for emergency repairs to Skylab's solar panels, for instance, and the Soviets for MIR pressure-shell repairs.

NASA has already used its RMS to recover complete spacecraft, including the recent capture of the Long-Duration Exposure Facility (LDEF), and for EVA support, such as during the capture and repair of the ailing Solar Max satellite. It plans to use a combination of EVA and robotics for the assembly and maintenance of the International Space Station 'Freedom'.

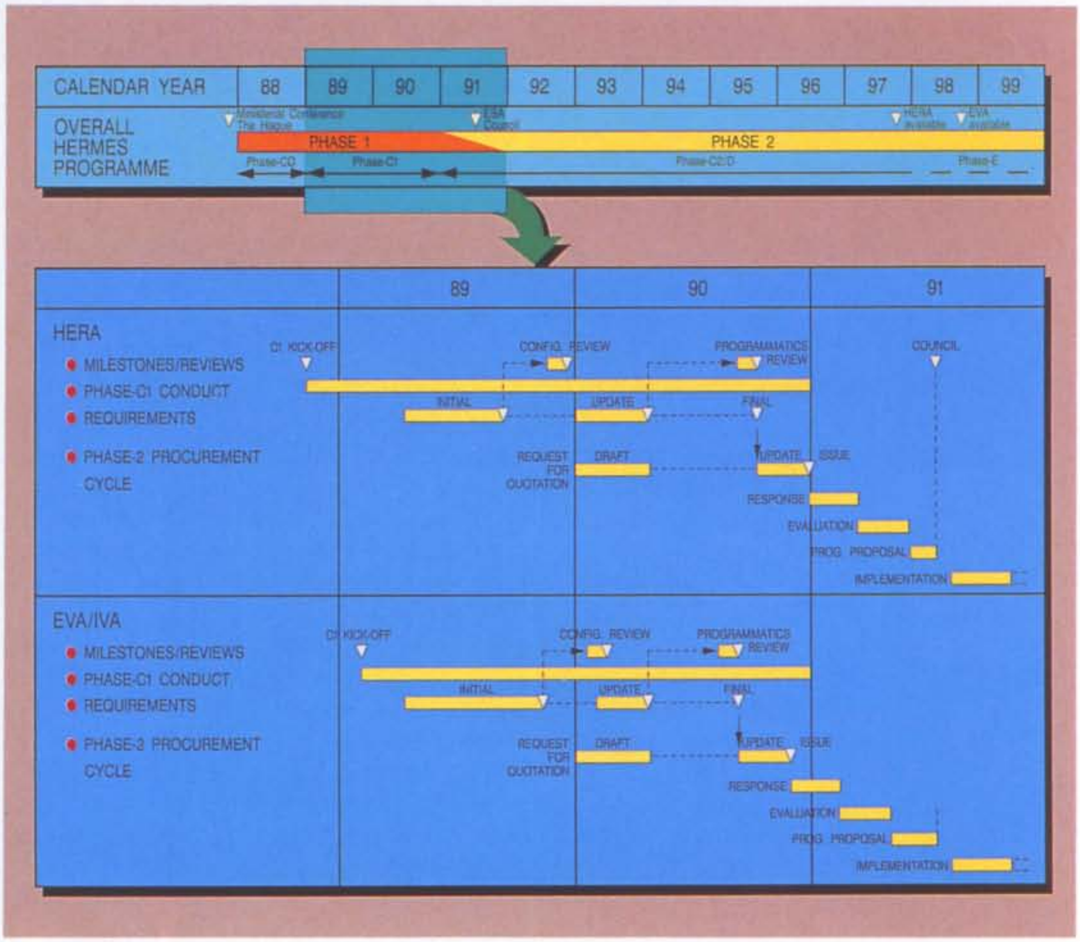
The Russians have used their robot arm to support the assembly of additional elements on MIR, and they have also used EVA to enhance that Station's capabilities, including the assembly of additional solar arrays.

There is therefore considerable experience to demonstrate that external intervention capabilities, both human and robotic, are an important and integral part of the space-exploitation scenario.

The European aims

Europe is currently well behind in terms of practical experience in external servicing. However, one of the directives that the Agency was given by the Council Meeting at Ministerial Level in The Hague in 1987, for the next generation of its programmes, was that Europe should strive for autonomy in space and therefore develop its own technologies wherever possible, rather than rely on those of its contemporaries. Consequently, allied to the development of Hermes and Columbus, ESA has embarked upon the establishment of both an EVA and a robotics capability as an integral part of the Hermes Programme. In undertaking these ventures, ESA has looked at both the NASA and Soviet approaches, and is attempting to build upon that prior experience using state-of-the-art technologies, thereby substantially

Figure 2. Main phases in the Hermes Development Programme and details of EVA and HERA Phase-C1 planning



bridging the gap between their and our experience.

The current programmes

Since EVA and HERA are both parts of the Hermes Programme, their development follows the same methodology, standards and schedule. The main phases in Hermes' Development Programme are summarised in Figure 2, together with a more detailed breakdown of the current Phase-C1's of the associated EVA and HERA activities. These Phase-C1 activities are intended to support the generation of the data needed for the ESA Council to give the go-ahead for the complete Hermes Programme at its June 1991 meeting.

Figure 3. The HERA and EVA Phase-C1 objectives

- CONSOLIDATION OF DEFINITION TO CONFIRM THE APPROACH, SAFETY AND PERFORMANCE OBJECTIVES
- REDUCTION OF TECHNICAL RISK TO ACCEPTABLE LEVELS
- ESTABLISHMENT AND DETAILING OF INTERFACES TO HERMES AND COLUMBUS
- CONFIRMATION OF SCHEDULE AND FINANCIAL ASPECTS

Short-term objectives

Both the EVA and HERA activities are presently some two thirds of the way through Phase-C1, the primary objectives of which are indicated in Figure 3. These objectives, which are consistent with those of the corresponding Hermes Phase-C1 activities, can be characterised as follows:

Design consolidation

- to iterate the operational scenarios and refine the specific functional and performance requirements;
- to conduct trade-off studies for the various design options, perform detailed design analyses, and iterate these with the requirements, interface definition and costs.

Technical-risk reduction

- to identify specific risk areas and concentrate extra effort on developing breadboards and prototypes in order to gather empirical data to back up the more classical design and analysis efforts.

Advance interface definitions

- to establish, via frequent Interface Working Group meetings, the technical, programmatic (schedule, deliverables, etc.) and operational interfaces with Hermes and with Columbus and thereby support the design and procurement process.

Confirm schedule and financial aspects
- to establish a design and development plan based on the technical concept and the delivery milestones;
- to identify necessary verification facilities;
- to finalise a detailed product tree and work-breakdown structure;
- to establish detailed costing, planning and work-sharing corresponding to the above, traceable to the technical requirements.

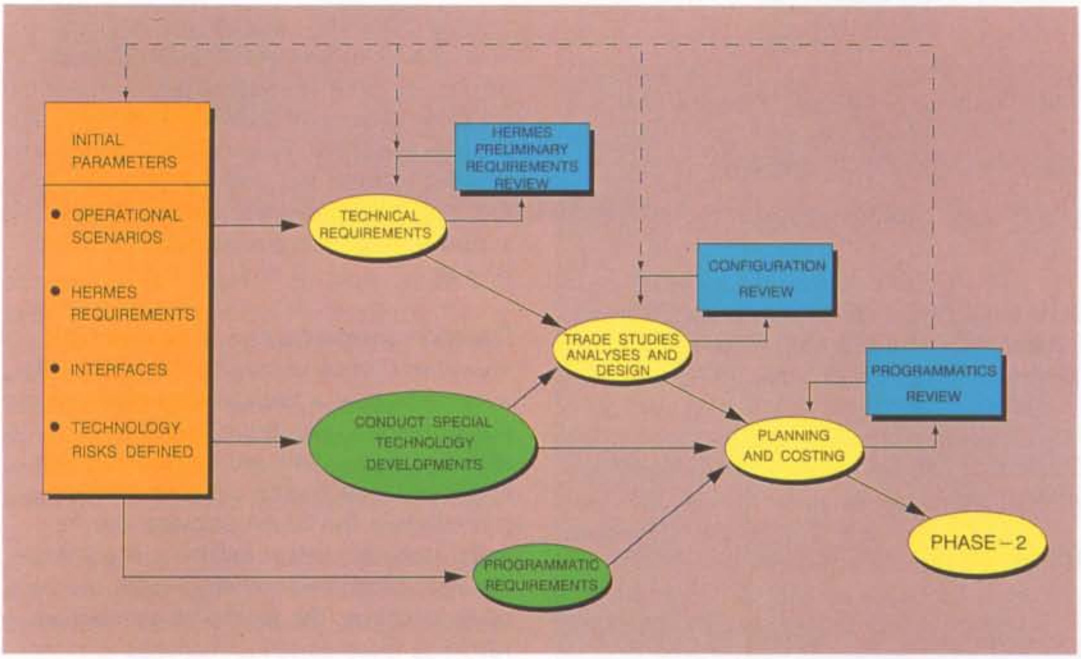


Figure 4. The Phase-C1 methodology

Phase-C1 methodology

To achieve the objectives outlined above, a specific programme logic based on a sequence of formal reviews has been established, the principles of which are summarised in Figure 4. Starting from the database built up during earlier studies, the operational external-servicing scenarios, the Hermes system requirements and the external interfaces have been distilled into a set of specific EVA and HERA technical-requirements documents. These were submitted to the Hermes Preliminary Requirements Review (PRR) and the refined requirements emerging therefrom were used to trade-off design options, for detailed system and subsystem analyses, and for computer-aided-design activities.

This work, and the progress in the activities related to the special technology-development efforts, has been documented in the form of a data package for a 'Configuration Review', to examine compliance with the basic requirements. The output from the Configuration Review is an agreed technical reference forming the basis for the generation of a product tree, work-breakdown structure and development planning, enabling detailed costing to be established.

This data, combined with updating of the technical reference and an assessment of the results of the technology programmes, will be submitted to the Agency in the form of a Programmatics Review data package. The results of this Review will then be compared with the technical requirements and the overall Hermes cost and planning targets, to ensure that programme aims are being maintained and confirmed. This will allow the proper data to be generated for the ESA Council, as well as enabling the procurement documents for Phase-2 implementation (the Request for Quotation and the corresponding proposal) to be produced ready for Phase-2 initiation.

Current status

Both the Hermes and Columbus Programmes have, by their very nature, had rather dynamic histories to date. In striving to arrive at the optimum feasible design solutions, it has been confirmed that, for external-servicing purposes, the robotic (HERA) contribution is best focussed on predictable, standard tasks, with EVA being the best solution for those tasks requiring the innovative intervention of the astronaut. Operationally speaking, the HERA can perform tasks in parallel with other internal servicing activities, as its operation requires only the (part-time) support of one crew member. On the other hand, safety considerations, combined with the smallness of Hermes' crew, dictate that when an EVA sortie is being performed all other servicing tasks must be put on hold.

These overall aspects, together with the design evolution of Hermes and Columbus, have led to the following current status in HERA and EVA development:

HERA

The technical requirements for HERA are summarised in Figure 5. Initially, the Hermes Robot Arm was foreseen as being similar to that of the US Space Shuttle, namely an arm permanently attached to Hermes and deployed from its (unpressurised) cargo bay to perform its servicing tasks. Today, Hermes has no such cargo bay and the HERA, once launched with Hermes, is to be deployed to an operational 'base-point' on the Columbus Free-Flying Laboratory. It will be controlled from Hermes' cockpit during the space-plane's twice yearlyvisits to the Laboratory, where it will be stowed in a 'hibernation mode' between such visits. The HERA will therefore be in-orbit based and maintained, and will have a design lifetime of 10 years.

Figure 5. HERA technical-requirements summary

- LAUNCHED INITIALLY BY, AND OPERATED FROM, HERMES
- RELOCATABLE TO COLUMBUS FREE-FLYING LAB.
- OPERABLE IN AUTOMATIC AND OPERATOR-CONTROLLED MODES
- OPERATIONAL TASKS TO INCLUDE INSPECTION, ORBITAL REPLACEMENT UNIT (ORU) EXCHANGE, ASTRONAUT TRANSFER, LARGE-ITEM MANIPULATION, AND EVA SUPPORT
- STOWED ON THE COLUMBUS FREE-FLYING LABORATORY BETWEEN HERMES VISITS
- 10 YEAR IN-ORBIT DESIGN LIFE, MAINTAINABLE FOR 30 YEARS
- COLLISION-AVOIDANCE SOFTWARE AS SAFETY BACKUP
- VERIFIABLE ON GROUND
- OPERATIONAL RELIABILITY OF 0.99 OVER 10 YEARS

In order to optimise the HERA's reach envelope for a given arm length, it will be 'relocatable' in that it will be able to move from one base-point to another and thereby change its sphere of operation. This has led to a symmetrical arm configuration, with the arm end-effectors able to serve both as supports and dexterous manipulator wrists (Fig. 6).

Depending upon the task in prospect, the crew can choose to operate the HERA fully automatically, in a tele-operated mode, or in a third mode in which the operator can manipulate each joint individually. To avoid the need for dedicated onboard computers and displays, the HERA software and its man/machine interface will be integrated into Hermes' cockpit equipment, which has many other functions. The functional architecture resolving these complex interfaces is shown in Figure 7.

The typical operational tasks mentioned previously form a menu of capabilities that will allow the mission planners and crew to

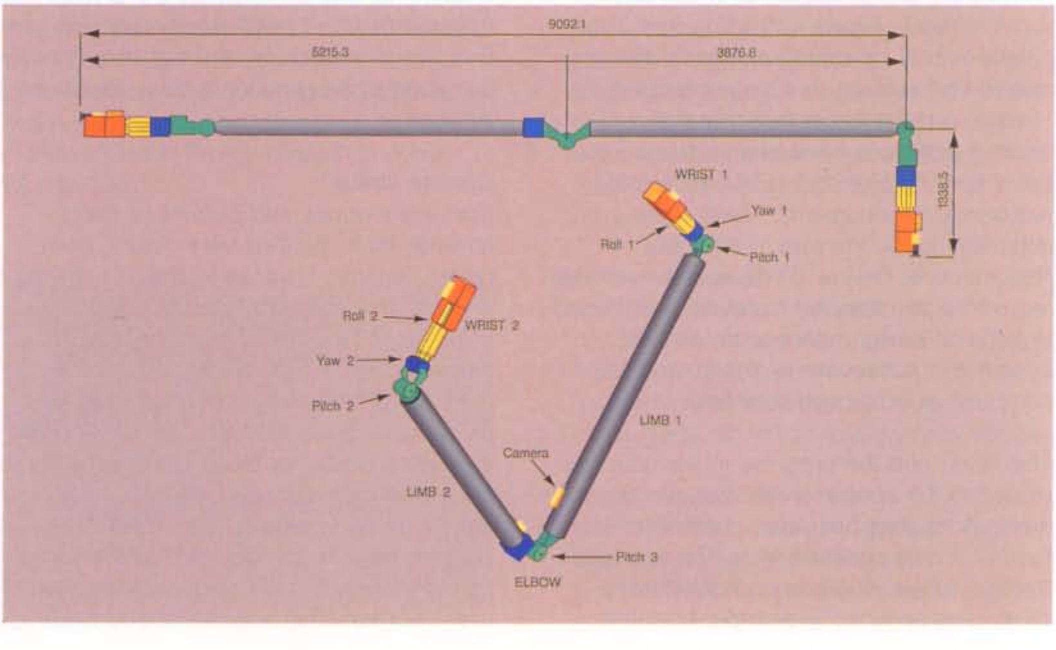


Figure 6. The HERA robotic arm

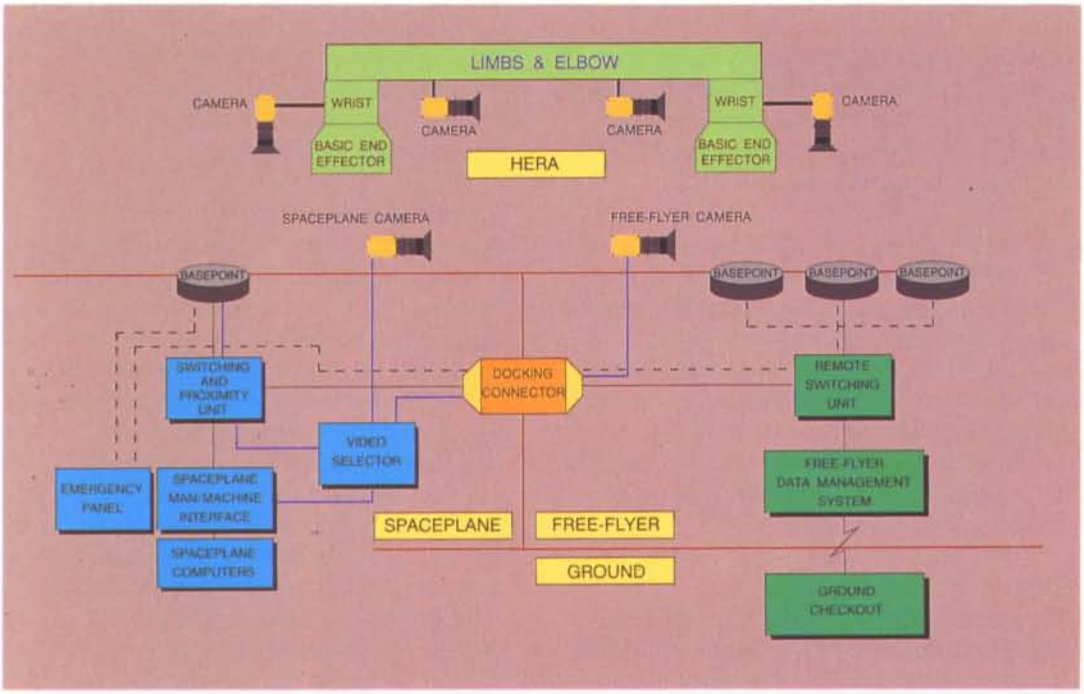


Figure 7. The HERA functional-control architecture

address a wide range of activities. At the heart of this concept lies the interface between the item to be manipulated and the end of the arm, the so-called 'Basic End-Effector'. This item's development is recognised as being one of the most critical, and it has therefore been the subject of extensive breadboard development (Fig. 8).

The 10.5 m long HERA arm must be capable of moving itself and other objects around in the vicinity of highly sensitive and expensive spacecraft such as the Columbus Free-Flying Laboratory itself. The crew will have no direct view of the arm whilst it is operating, and must rely on video-camera images and display information to check on its position at any given moment. To ensure that it does not inadvertently stray and cause damage, there is sophisticated 'collision-avoidance' software built into the HERA system to supplement the video/display data. Verification of the controllability and safety of the arm's operation is clearly a critical area, and a 'HERA Simulation Facility Pilot' (HSF-P) has therefore been developed in order to check the system's operating characteristics on the ground from a Hermes cockpit mockup (Fig. 9).

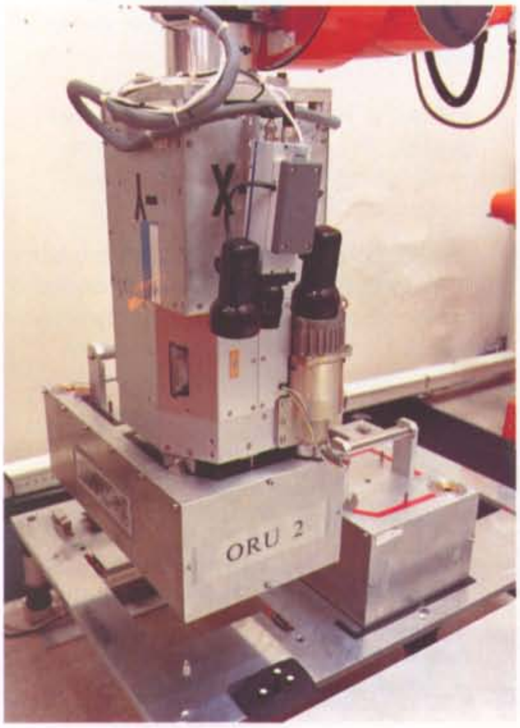


Figure 8. The HERA basic end-effector

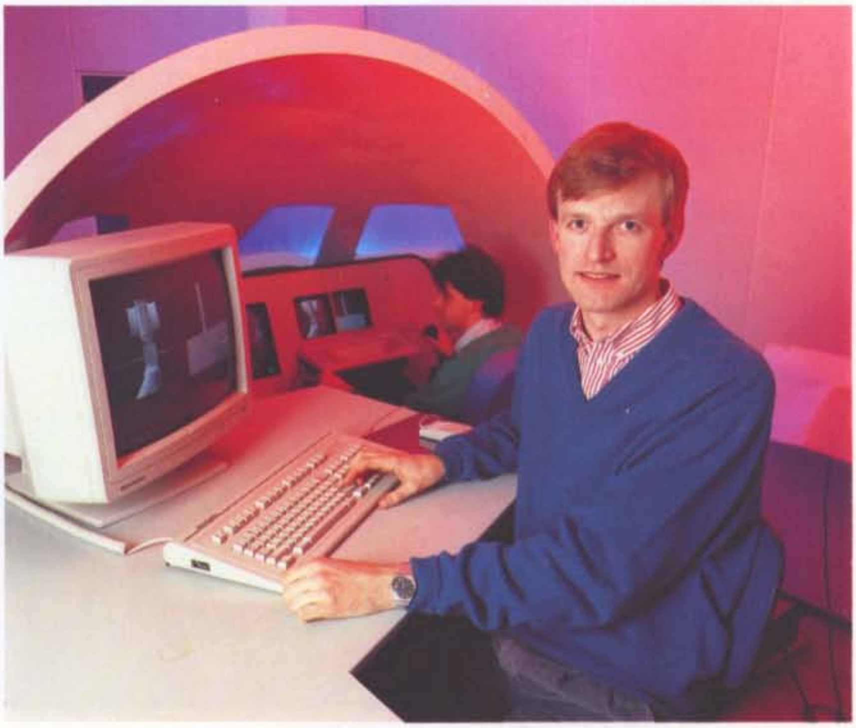


Figure 9. The HERA Simulation Facility Pilot (HSF-P), at Fokker, in Amsterdam (photo. courtesy of Fokker BV)

As a further guarantee of safe orbital operation, stringent qualitative safety and quantitative reliability requirements have also been imposed, and these targets are continuously reviewed to check the HERA design's compliance.

The HERA Configuration Review was successfully conducted at the end of 1989. The latest changes to the Columbus Free-Flying Laboratory are currently being evaluated to see if they substantially affect the HERA requirements or design concept. Meanwhile the focus is shifting to the provision of the programmatics data needed for the next review in the third quarter of 1990.

EVA

The technical requirements for the EVA system are summarised in Figure 10. Initially, it was intended that EVA activities would be a requisite link in the Hermes safety chain (as a contingency mode for reconfiguring the spaceplane prior to re-entry, for instance in the event of a failure to stow deployables). This requirement has subsequently been dropped, partly as a result of the elimination of the unpressurised cargo bay, partly as a result of optimising the inherent safety of the spaceplane, and partly as a result of wishing to carry EVA equipment only when a servicing task is foreseen.

Figure 10. EVA technical-requirements summary

- LAUNCHED/RETRIEVED BY HERMES
- TWO-CREW-MEMBER OPERATION (NOMINALLY)
- 7 HOUR SORTIE DURATION (INCLUDING CONTINGENCY)
- TWO SORTIES PER HERMES FLIGHT
- ON-GROUND MAINTAINABLE
- OPERATIONAL TASKS TO INCLUDE ORBITAL REPLACEMENT UNIT (ORU) TRANSPORTATION AND EXCHANGE, TRANSLATION TO AND CORRECTIVE ACTION ON FAILED EQUIPMENT
- DESIGN LIFETIME OF 30 FLIGHTS PER SUIT
- 500 HPA PURE-OXYGEN ATMOSPHERE INSIDE SUIT
- CONTINUOUS RADIO-FREQUENCY COMMUNICATION WITH SPACEPLANE
- AUTONOMOUS EXTERNAL OPERATIONS (NO UMBILICAL)
- VERIFIABLE ON GROUND
- 0.95 PROBABILITY OF SUCCESSFUL OPERATION DURING A MISSION
- 0.9995 PROBABILITY OF SAFE CREW RETURN FROM EVA SORTIE

Nevertheless, to ensure that EVA will be available whenever it is needed, the system is being designed for the full Hermes mission lifetime of 30 flights. It is being sized to support two sorties per flight, each of 7 h duration (including one hour of contingency). For safety reasons, EVA sorties will normally be conducted by a pair of astronauts, in two-way communication with the third crew member, who will remain inside Hermes. To minimise the amount of 'pre-breathing' necessary by the astronaut (to avoid experiencing the 'bends') and yet maintain sufficient dexterity when suited, a suit operating pressure of 500 hpa has been chosen. The suits are adjustable in size to avoid needing a dedicated suit for each potential EVA astronaut.

The suit itself (Fig. 11) is functionally autonomous from the spaceplane, with only a safety tether to the mother craft, rather than an umbilical carrying power, oxygen, etc. The suit's main components are the enclosure itself, the life-support equipment (backpack), and the information and communications package. Part of the latter is contained in the chest pack, from which the wearer can control certain suit environment parameters and have data displayed to him. The EVA system is completed (Fig. 12) by a control panel built into the Hermes Resource Module (MRH), which will be used to check the suit's readiness prior to egress from the spaceplane.

A number of the suit's features have been singled out for special attention prior to commitment of the final design. These include:

— gloves: construction techniques are being evaluated to determine the best design of glove consistent with the dexterity/tactility needed under the 500 hpa pressure differential;

— joints and bearings: shoulder-joint types are being evaluated to determine the optimum combination of dexterity and pressure integrity;

— materials: several candidate soft materials are being evaluated to investigate their integrity, durability, wear-resistance and thermal/micro-meteoroid-protection capabilities;

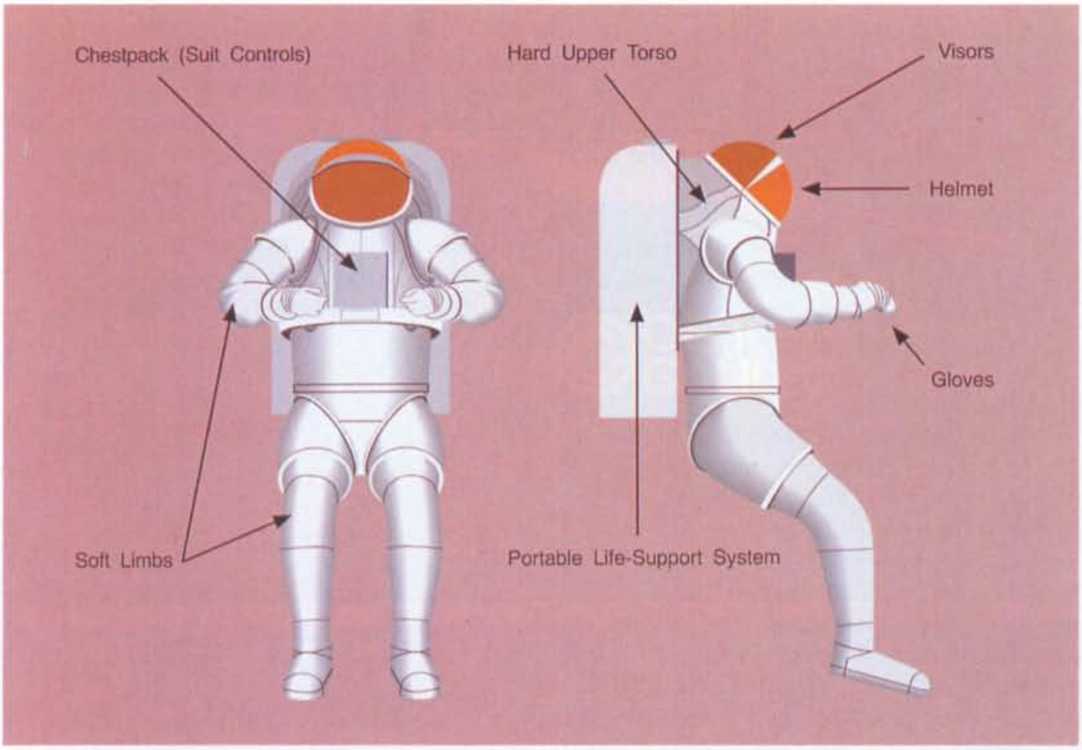


Figure 11. EVA spacesuit layout

- biomedical sensors: evaluation of those human physiological parameters that need to be continuously monitored, and designs for the associated sensors and data-transmission equipment are underway;
- voice processing: breadboarding of a voice processor to evaluate the feasibility and efficiency of using voice commands to control certain suit parameters (such as temperature and airflow);
- environmental control components: breadboarding of the high-pressure oxygen supply and control equipment, the carbon-dioxide control and monitoring equipment, and the water sublimator is being carried out to determine performance parameters.

Safety is of paramount concern in the design of the EVA system and an independent parallel study on the application of new safety-analysis techniques using the EVA suit

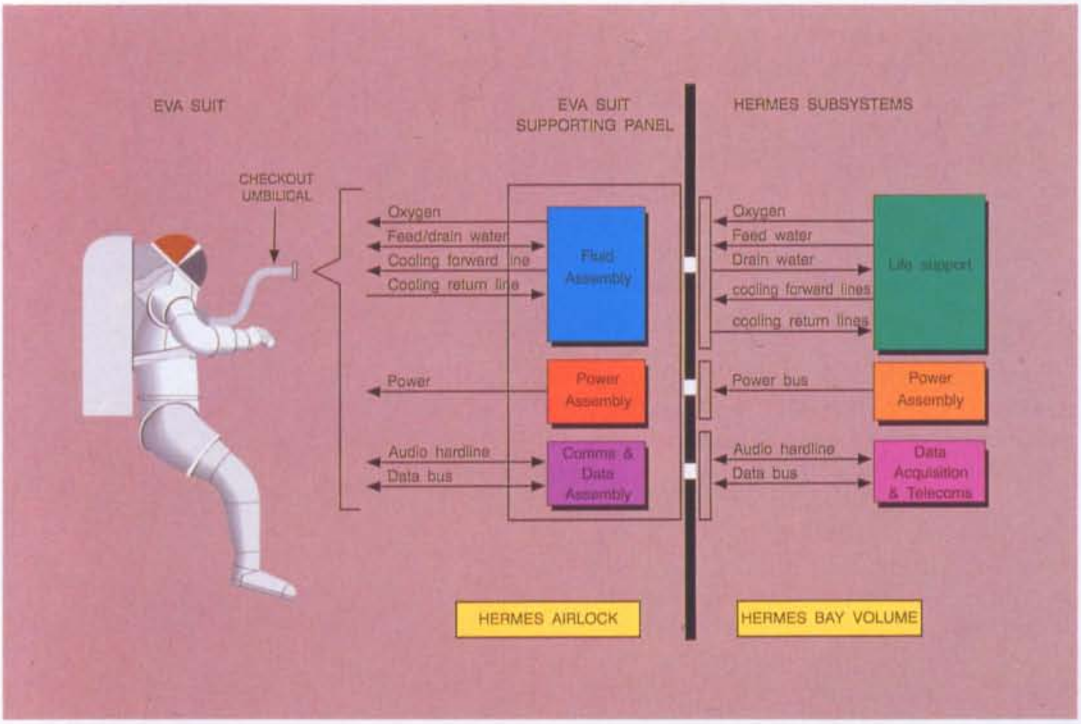


Figure 12. EVA system functional architecture and interfaces

as the candidate system has been successfully performed. This exercise has demonstrated both the effectiveness of the analysis technique (now being standardised by ESA for all safety analyses), and the basic integrity of the EVA system.

The EVA System Configuration Review was conducted in January 1990 and now, as for HERA, attention is focussing on the programmatics data generation.

Future plans

The short-term future is obviously dedicated to the completion of the activities presently under contract and the preparations for the Hermes Phase-2. Specific outputs of the current phase on HERA will include the development of a non-real-time HERA simulator (to enable detailed engineering analyses to be performed in Phase-2), the further development of the Hermes–HERA man/machine interfaces, and a pilot version of a HERA Test Facility.

Within the present EVA programme, a complete suit demonstrator will be constructed, CAD tools will be developed to support operational analyses, and the facilities required for verification will be baselined. For both HERA and EVA, the first steps towards establishing the necessary programme for operator/crew training will be established.

In Phase-2, in addition to the development and delivery of the flight units, training and operational-procedure development will be undertaken and the ground infrastructure (including engineering support for the operational phase) will be established.

A number of longer term future growth capabilities have already been identified and requirements established to ensure compatibility of the first-generation products with this growth scenario. Such capabilities include the expansion of HERA operability/control options (e.g. control from the ground or from the in-orbit-based infrastructure, in addition to that from Hermes), and the incorporation of propulsion/transportation functions and enhanced communications functions for the EVA system.

Conclusions

By the end of the decade, Europe will have a space-based robotic capability comparable with those foreseen by the other space powers. It will also have an EVA system (if not the associated manoeuvring units) based on more advanced technology than that of the United States, and at least comparable with that of the Soviets. These two developments will together provide the external servicing capability that is mandatory for the operational phase of the Agency's future space-infrastructure programme. Moreover, this capability will be suitable for adaptation/growth to support any longer term, next-generation, European infrastructure developments well into the next century.

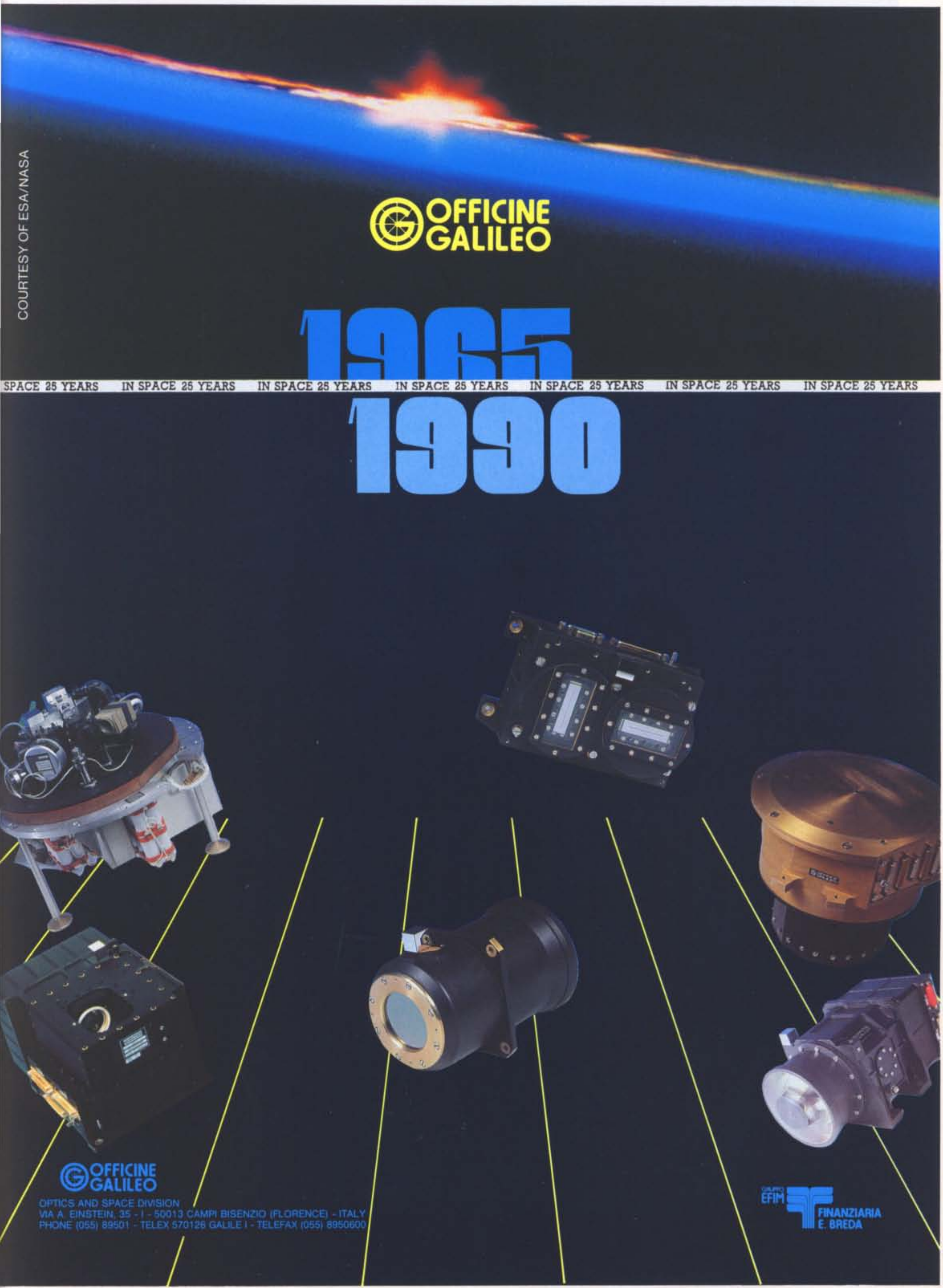


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Figure 1. Artist's impression of Artemis, the Advanced Relay and Technology Mission Satellite

ESA's Advanced Relay and Technology Mission

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The Advanced Relay and Technology Mission (known as 'Artemis') is ESA's latest communications-technology demonstration satellite. Its main payloads will prove the technology for advanced data-relay and land-mobile applications and pave the way for future operational services in these domains. It will also provide a flight opportunity for experimenting with new technologies, such as ion propulsion, which can be used to improve the performance of future European communications platforms.

Programme description

The Advanced Relay and Technology Mission is ESA's latest communications-technology demonstration satellite, in the tradition of OTS and Olympus. The programme consists of the development, launch and operation of a single geostationary satellite, and includes advanced communications payloads with data-relay, mobile and fixed-service applications.

The value of this kind of experimental communications mission has been convincingly demonstrated in the past by the success of the OTS satellite, which has provided the technological basis of the ECS and Marecs satellite series, and thereby supported the creation of the EUTELSAT and INMARSAT organisations. OTS was also the forerunner of a number of national missions such as DFS, Skynet and Telecom, and the European Eurostar platform.

Although space communications is becoming an increasingly commercial affair, the development and flight risks associated with new technologies are considerable, and industry and service operators are reluctant to embark upon new systems within the scope of their commercial activities. Market studies show that the time is now right for a communications-technology mission to provide European industry with an opportunity to improve and renew its technological and system capabilities, and so prepare it for the commercial markets of the next decade. Similar demonstration missions are also planned in the USA and Japan (in particular, ACTS by NASA and ETS-VI by NASDA).

The payload configuration of the Artemis satellite has resulted from a broad range of mission studies conducted in the framework of the Agency's Payload and Spacecraft Development and Experimentation (PSDE) Programme over the last few years, when the mission was referred to as Sat-2. The baseline payloads, which have been selected for their potential to promote new services and improve the competitiveness of European industry, are:

— a laser optical data-relay and communications experiment, providing a high-data-rate link with low Earth-orbiting or geostationary satellites
— an S-band, high-gain, multiple-access data-relay payload, for demonstration of the technology needed by future data-relay services for medium data rates
— an advanced L-band land mobile services payload, using a large reflector to provide spot beams and exercise frequency re-use
— a number of spacecraft technology experiments, such as the ion-propulsion package and nickel-hydrogen batteries, for improving platform capabilities; other experiments will monitor critical payload interfaces and platform environments.

Other payloads that will be breadboarded under the preparatory programme, and retained as options for Artemis, or other future missions, are:
— an on-board processing payload for baseband switching of digital communications traffic between spot beams, and
— a millimetre-wave (60 GHz) data-relay payload.

It is intended to use a European geostationary communications platform of an existing design, such as Eurostar or Italsat, suitable for a dual launch on an Ariane-4 vehicle. The spacecraft platform and payloads have a design lifetime in excess of ten years and, based upon use of the ion-propulsion package, the full station-keeping potential of the mission is also greater than ten years.

Phase-B2 of the programme started in July 1989 with Selenia Spazio (Italy) as prime contractor. The definition of the major payloads was completed by the end of 1989, and the more critical breadboarding activities started. Spacecraft-configuration studies were also completed, pending a choice of platform.

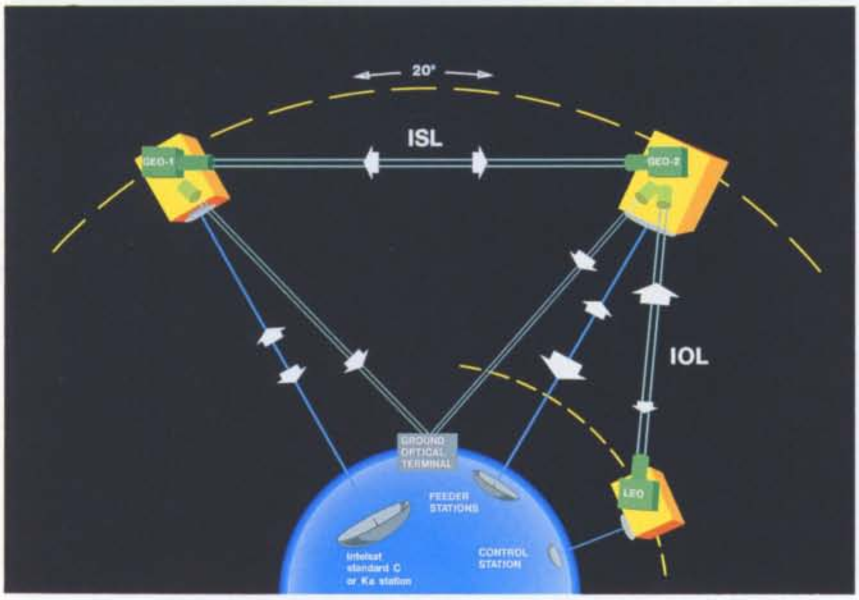


Figure 2. The Silex system configuration

Because some of the payloads selected for Artemis are intended to exercise the advanced technology needed for future data-relay services, the programme has been combined with the Data-Relay System (DRS) into a coherent telecommunications programme (DRTM) with two programme elements.

The Enabling Resolution for this programme was approved by the Agency's Council at its meeting in October 1989, and legal steps for subscription to the Declaration have been initiated. Subject to final programme approval, the planned launch date for Artemis is 1994.

Advanced data-relay payloads

The first-generation operational DRS is aimed at providing a reliable service with a guaranteed performance to the elements of the European space infrastructure to be deployed in the second half of the nineties. It will do so by using proven technology to meet the various user requirements.

Consequently, in the baseline DRS configuration, as currently studied within the DRS Preparatory Programme, high-data-rate requirements, corresponding typically to the needs of Earth-observation platforms, would be served by Ka-band data-relay links. The low-data-rate requirements arising, for example, from Columbus elements and Hermes in emergency mode, would be served by S-band single-access links; i.e. for each user, a separate steerable antenna is needed on the DRS satellite, with a consequent limitation on the number of users who may be served simultaneously.

It is believed that for future data-relay services, there will be an increased emphasis on very high-data-rate links, and an increased number of low-data-rate users. This user scenario would then benefit from the introduction of alternative data-relay technologies, in particular laser-optical communication systems for high data rates, and S-band multiple-access techniques for the low- to medium-data-rate users.

The purpose of the Artemis mission is to develop and demonstrate these advanced technologies in orbit, in preparation for future DRS applications, as of necessity they contain an element of development and operational risk.

The 'Silex' Optical Communications Data-Relay System

The data-relay systems of the future will require links capable of handling very high data rates, of the order of several hundred megabits per second. For applications with return links from low Earth orbit (LEO), for example, this requirement stems from the development of very-high-resolution instruments for Earth observation, such as synthetic-aperture radars, as well as the policy of grouping many payloads on large carriers, like the Columbus Polar Platform.

Relay links between geostationary (GEO) satellites are also of some interest, for interconnecting the data-relay networks of the USA, Europe and Japan, or for intercontinental traffic (between INTELSAT and EUTELSAT networks, for example). With the anticipated growth in laser diode power and receiver sensitivity, free-space optical technology holds great promise for providing these very high-data-rate links, with less demand on spacecraft resources, such as mass and power, than radio-frequency (RF) systems.

The purpose of 'Silex', the Semiconductor Laser Intersatellite Link Experiment, is to develop all of the elements for such a space-based optical-communications system, and to demonstrate its capabilities in an experimental and pre-operational mode.

The Silex system configuration (Fig. 2) is designed for experimentation with two-way data links for either LEO or GEO applications. Two similar optical terminals will be built, with the GEO terminal installed on Artemis as relay satellite, and the LEO terminal on Spot-4, one of a series of Earth-observation platforms in the French national programme. Although no geostationary partner satellite has so far been identified, the GEO terminal will be able to point along the geostationary orbit, should a partner be found at a later date. The possibility of cooperation with other agencies such as NASA, INTELSAT and NASDA is being pursued.

With current technology, Silex will provide a 65 Mbit/s data rate over the optical return link from Spot-4 which, after re-transmission via the Ka-band feeder link of the Artemis satellite, can be received by earth stations in the European coverage zone. For experimental verification of system performance, test signals will be generated in the LEO terminal and monitored by the ESA control and test station at Redu in Belgium (Estrack). An optical ground station in the Canary Islands is also under investigation, both for checking out the GEO terminal and for further communications experiments.

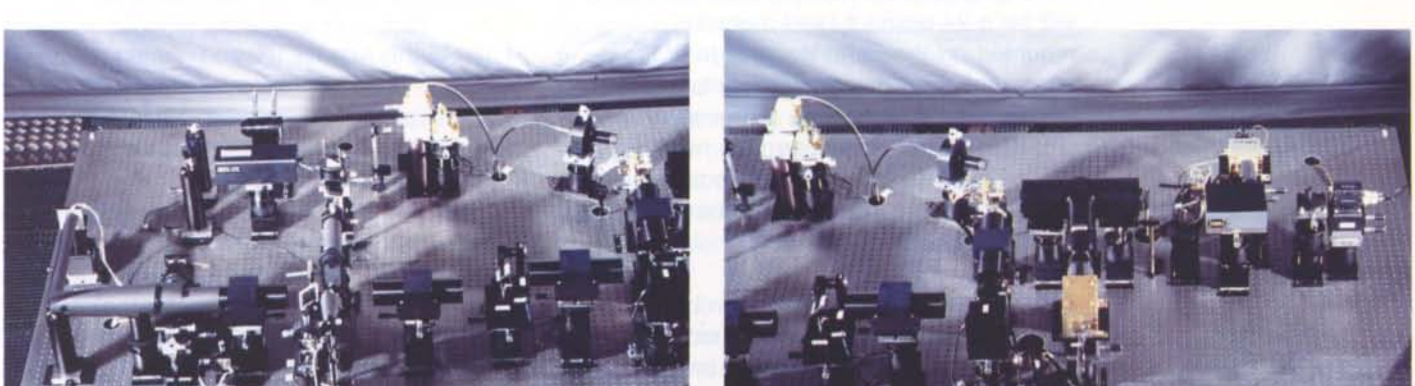
Under the terms of an agreement with CNES, the French national space agency, after an initial experimentation phase, a pre-operational service will be provided to Spot-4. For several orbits per day, Spot-4 image data will be transmitted over the relay link for reception by an earth station at the Spot image-processing centre in Toulouse.

Each terminal consists of an optical telescope of 25 cm diameter, mounted on a coarse pointing mechanism. This has a large pointing range to cope with the wide variation in line of sight from LEO to GEO. The optical power source is a laser diode operating at a wavelength of 830 nm, with a peak power output of 120 mW. On the receive side, the data detector consists of a silcon-avalanche photodiode, followed by a low-noise trans-impedance amplifier.

Within the optical assembly, a fine-pointing mechanism of orthogonal mirrors, driven electrically, copes with the high-frequency motion and also provides a search pattern to lock onto a beacon during link acquisition. The acquisition and tracking sensors are charge-coupled matrix devices (CCDs). It will readily be appreciated that, as the optical beam is only 0.0004° wide, beam control for tracking and acquisition under all conditions of host spacecraft motion is one of the most challenging tasks confronting free-space optical communications.

The terminal design is well advanced and system performance has been verified by means of a system test bed (Fig. 3). The terminal weighs 90 kg and has a power requirement of 110 W. Currently, the performance of this experimental payload is not dramatically competitive with RF systems, but there are several promising developments in optical technology that can bring performance improvements of up to 20 dB. These include increased laser-diode powers, use of the heterodyne principle, and wave-division multiplexing. The next generation of optical terminals will therefore be smaller and more powerful, with telescope diameters

Figure 3. The Silex system test bed



around 10 cm and terminal masses of typically 50 kg. Higher data rates of 500 Mbit/s to 1 Gbit/s will also be possible.

The S-Band Data-Relay Payload (SDR)
To overcome the limitations inherent in a data-relay system based upon single-access links, the advanced SDR payload uses phased-array technology, which allows several independently steerable links to be established simultaneously, i.e. multiple access. Moreover, it provides the high gain required by future spaceflight systems. A payload of this kind is also under consideration by NASA for its second-generation Tracking and Data-Relay System (TDRS).

The baseline performance for the SDR payload is a G/T of 9 dB/K and EIRP of 44 dBW, with a scan capability up to 10° from the Earth's centre. The SDR will provide a single forward link from a user earth terminal towards LEO of up to 300 kbit/s. In the return link, the SDR payload is capable of supporting two users simultaneously, each tracked independently, with data rates of up to 3 Mbit/s. The antenna concept is, however, capable of providing an increased number of accesses in both the forward and return directions, for future operational versions. Links are established over a receive and transmit bandwidth of 10 MHz in the frequency range 2200–2290 MHz. Range and range-rate measurements will enable the orbit of the user spaceraft to be determined.

The antenna baseline design consists of two independent phased arrays (apparent in Fig. 1), one for reception and one for transmission. The receive array will consist of typically 100 radiating elements (Fig. 4), mounted on one or more panels deployed from a side wall of the spacecraft. Each of these elements is connected to a low-noise amplifier (LNA) inside the spacecraft via a flexible transmission line. The transmit array will be a 24-element fixed assembly, mounted on the Earth-facing side of the spacecraft. The antenna elements are each fed by a 2.5 W solid-state power amplifier (SSPA). Separate beam-forming networks — one per user and one per receive and transmit beam — are used for beam control, using phase adjustment only.

This payload concept has a number of advantages and may easily be extended to any number of simultaneous accesses. Performances in terms of G/T and EIRP can easily be upgraded or reduced if so required. The payload has a nominal weight of 130 kg, and requires about 300 W of DC power.

A number of potential users have been identified for a demonstration. One is Spot-4, and the inclusion of an experimental S-band transponder in its payload complement is being studied. A user space terminal has been identified based upon a spread-spectrum transponder developed within the Agency's ASTP programme, and an existing omni-directional antenna design. Such an experiment would be valuable in connection with Silex, offering continuous and enhanced telemetry coverage and ranging data.

NASA has also indicated its willingness to participate, using any of the suitable LEO missions currently supported by TDRS.

Figure 4. Radiating element of the advanced S-band Data-Relay Payload (SDR)

Other ESA missions under consideration are Eureca re-flights and the Aristoteles spacecraft.

Later in the Artemis mission, continued demonstration with Columbus elements will be possible. Particular emphasis will be given to validation of new ground-segment concepts in preparation for DRS.

The L-band Land Mobile Payload (LLM)
In Europe, as in North America, mobile communications is a rapidly growing market. Although a European cellular network using UHF relay stations is planned, with deployment around major cities and along highways taking place in the 1990s, it is likely that the least-populated areas of Europe will

still be without a mobile service for a long time to come.

Indeed, several market studies of land mobile services have shown that a considerable niche market exists, particularly in the road-transport industry, the business activities of which cover the entire European continent, the Middle East and North Africa. Other users include the railways and inland-waterway transport, amounting to a total potential market of up to one million units.

The service requirements of this user community are for voice, message and data transmission, with a preference for private networks, although a significant minority will also require access to the public networks. This demand is best satisfied by a satellite-based communications system, which can also be integrated with the cellular system. A system capacity of several thousand channels is required and, in view of the limited bandwidth allocated for land mobile satellite services, frequency re-use techniques must be explored.

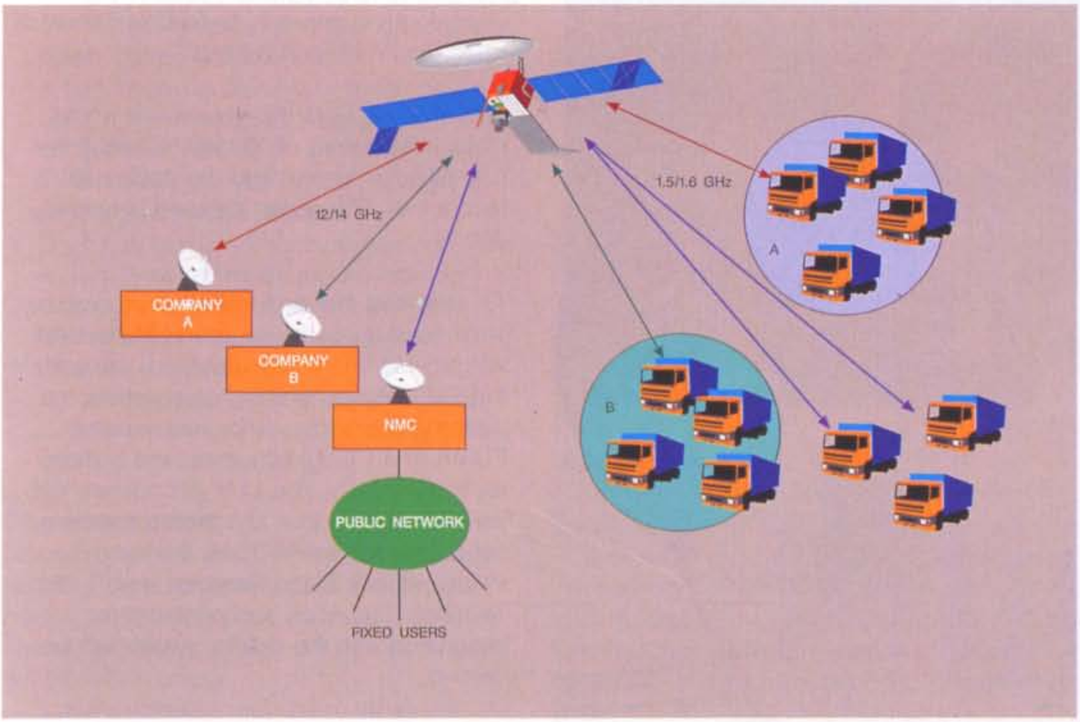


Figure 5. Land Mobile Satellite System (LMSS) configuration

A typical land mobile satellite system (LMSS) configuration is shown in Figure 5. The LMSS will provide two-way communication between fixed earth stations and land mobile terminals installed in vehicles such as trucks, trains and cars. Communications between the mobiles and the satellites is at L-band (1.5/1.6 GHz) and that between the fixed earth station and satellite at Ku-band (12/14 GHz).

Such regional satellite systems are planned in the USA, Canada, Japan and Australia. With the de-regulation of Europe in 1992, there is therefore a definite possibility that non-European investors and manufacturers will attempt to exploit the single large European market so created.

In order to preserve the competitiveness of European industry in this field, ESA has developed a concept for an operational European Mobile System (EMS). A first-generation EMS payload with European coverage and limited capacity has already been defined, and may be flown on one of the EUTELSAT second-generation satellites or another host platform, such as Italsat-F2, in the next few years.

The advanced second-generation EMS will provide increased capacity by means of increased satellite radiated power and frequency re-use. It will also supplement and be integrated with the future European cellular system. The advanced technology needed to provide this second-generation capability will be developed and space-qualified by the L-band Land Mobile Payload (LLM) included in the Artemis baseline mission.

In order to obtain this increased performance (high G/T and EIRP), and also to provide for spatial frequency re-use, multiple spot beams are required over the European continental region, which calls for a large reflector on the satellite. The baseline foresees an inflatable reflector of 5 to 6 m diameter (Fig. 6), generating typically seven spot beams, each with an EIRP of 52 dBW and a G/T of 2.5 dB/K, and one 'Eurobeam' covering all European ESA Member States, Greece and Turkey.

The payload concept is reconfigurable such that one movable spot beam allows the coverage zone to be extended to North Africa. Adjustable frequency bands will also offer considerable flexibility in terms of redundancy and frequency re-use, and will allow the service to be adapted to any new developments in frequency allocation.

Figure 6. A space-rigidised inflatable satellite reflector (courtesy of Contraves)

Traffic-distribution changes, both short-term and long-term, require routing flexibility without wasting spacecraft resources. This will be achieved by applying highly efficient filtering techniques (bandwidth-switchable SAW filters) for economic use of bandwidth. In addition, advanced power-amplifier concepts are required to maintain the same drive level to all elements, independent of the traffic distribution, resulting in efficient use of electrical (DC) power.

The payload concept that has been selected is based upon a focal-fed offset reflector system, using an overlapping feed cluster. The feed elements and power amplifiers are connected in a so-called 'multi-matrix' arrangement, forming a hybrid transponder that has been patented by ESA.

This payload therefore contains a significant number of elements of the technology needed for future mobile systems for the World market, namely: a large reflector, a multi-element feed array, low-loss diplexers and filters, lightweight LNAs and SSPAs, a beam-forming network, switchable-bandwidth filters, and multi-port hybrids.

The baseline LLM design involves a total mass in the order of 160 kg, including the 6 m reflector system and the dedicated feeder link. The power demand is typically 600 W.

An extensive test and utilisation programme is planned. In particular, the LLM payload will provide spare in-orbit service capacity for the EMS first generation, demonstrate the performance of frequency re-use using FDMA and CDMA schemes, and traffic-routing flexibility. The LLM will operate with various types of low- and high-data-rate services, such as PRODAT, Standard-C, Private Mobile Radio Services, and Public Telephony Services, and concepts for integration with the cellular system will be verified.

Technology experiments

The technology experiments are aimed both at increasing platform capability and monitoring the platform environment for the more sensitive payload interfaces. In addition, there is a beacon experiment for the measurement of propagation characteristics at extra-high frequencies.

Platform enhancement

A technology mission presents an excellent opportunity not only to demonstrate the performance of new technologies, but also to benefit from the improvement in platform capability that results from their application. For example, the use of ion propulsion for station-keeping on communications satellites promises propellant mass savings of 100–200 kg, for mission lifetimes of 10–15 years. Commercial programmes cannot take advantage of ion propulsion until it is proven in orbit. However, on the Artemis satellite a suitably qualified ion-propulsion system is the operational baseline, and the equivalent propellant mass reduction can be used for other payloads.

By the same token, each of the technology experiments has been selected because it pays its way on the technology mission. These are:

- Ion propulsion, using two different technologies in a redundant operational configuration. The technologies are based upon national developments over the last 20 years in the United Kingdom and in Germany.
- European nickel-hydrogen batteries, using cell technologies developed in France and the United Kingdom and giving increased power during eclipse.
- A pattern-recognition star sensor, based upon a multi-head CCD system as flown on ECS-5, providing an optical reference for three-axis attitude control during the ion-propulsion operations.
- Dry-tuned gyros will replace floating gyros as a roll/yaw reference for the attitude-control system. Together with the star sensor, a more accurate yaw-sensing capability is achieved.
- Propellant-gauging experiments in order to optimise propellant management and improve mission planning.

Diagnostics package

Monitoring of the environment of the new sensitive payloads is essential to achieve a reliable design status for future applications. The diagnostics package chosen for Artemis will therefore include:

- a micro-vibration monitor, re-using the PSDE accelerometer installed on Olympus
- a pollution monitor, based upon the concept of the THP design installed on ECS-1 (using quartz-crystal monitors)
- a charging monitor, using surface-potential monitors
- an RF probe under investigation.

Other platform improvements identified from in-orbit experience with communications missions over the last few years will be given due consideration. One example is modified solar arrays with improved insulation properties, thereby avoiding losses of array power caused by micrometeorites, electrostatic discharges and radiation effects.

Propagation package

The propagation experiment consists of a transmit-only package, providing beacon signals at 44.5, 89 and 133.5 GHz. The antenna pattern will cover Europe and the output power will be sufficient to allow small earth stations to make flux measurements. This will enable the scientific community to investigate tropospheric attenuation in the 40–50, 90 and 140 GHz windows, and to establish reliable statistics in order to design and characterise future communications applications.

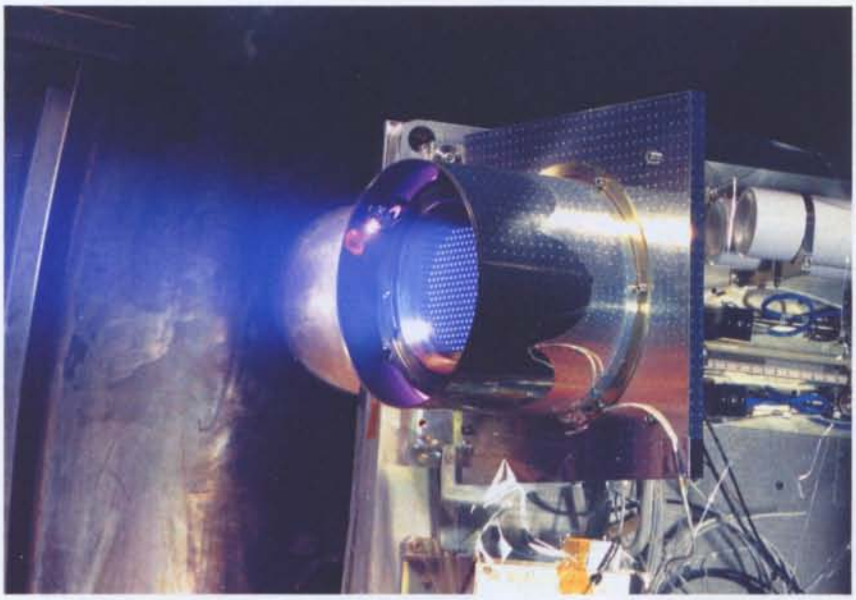
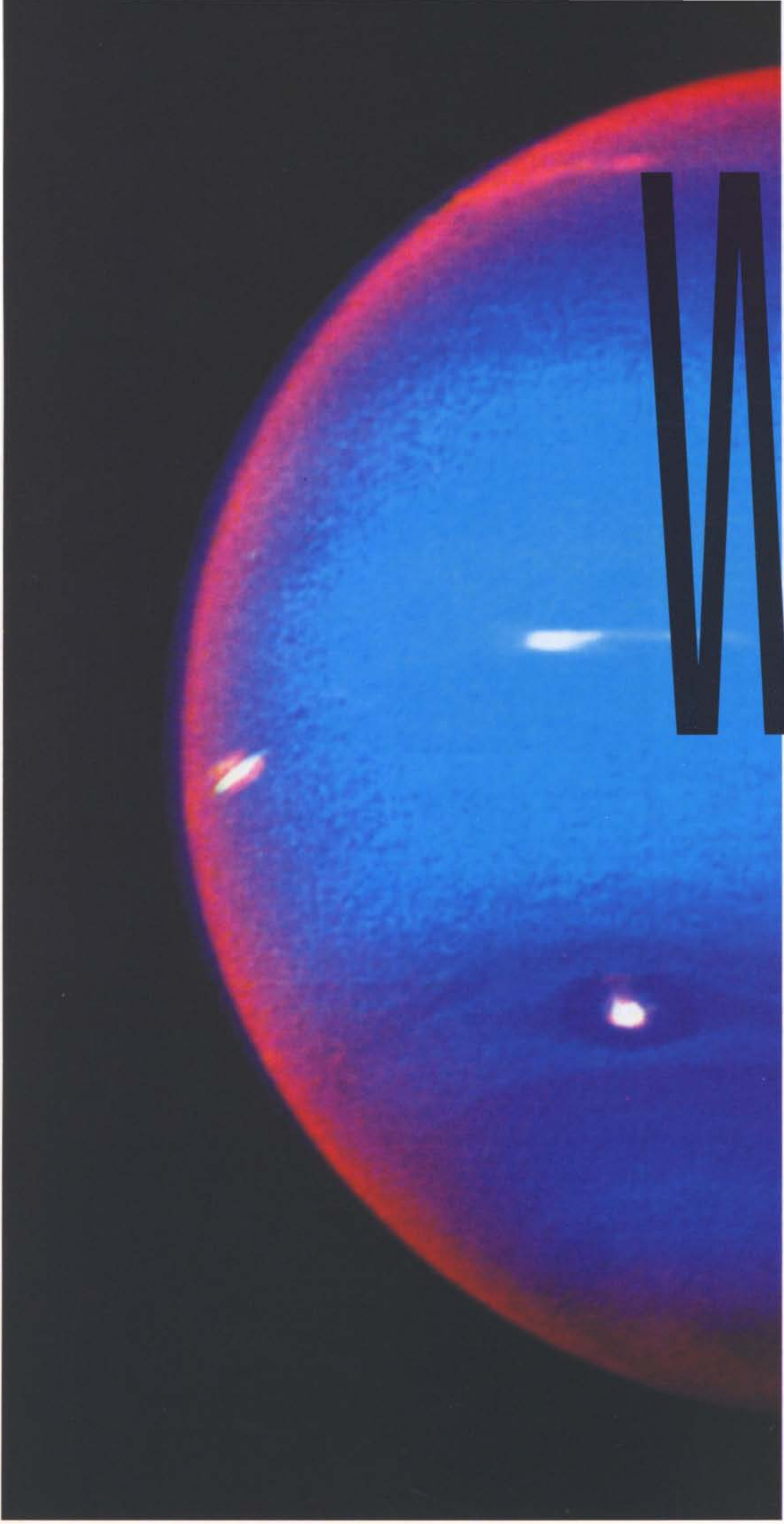


Figure 7. A RIT ion thruster undergoing test firing in a vacuum chamber (courtesy of MBB)

Conclusion

The communications-technology demonstration mission that has been described is well-balanced between the development of technology and system expertise, the promotion of new applications, and preparation to meet the needs of future operators. It also provides a flight opportunity for many important technological developments that have taken place in the last decade, supported under national and ESA programmes (such as ASTP) with a significant financial investment and industrial effort.

It is expected that full programme approval will be obtained in the near future, allowing a timely start to be made with the main development phase (Phase-C/D) of this important mission, which represents the culmination of considerable preparatory work, and which will enable European industry to maintain a competitive position in the space-communications market, faced with similar developments in the USA and Japan.



Supernova Remnants and the Exosat Satellite

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Exosat was launched on 26 May 1983 and operated for almost three years. A wide variety of X-ray emitting objects were observed, including the remnants of exploded stars. The study of these supernova remnants allows astronomers to examine the operation of scientific laws and theorems under physical conditions that are not reproducible on Earth. Exosat's payload of scientific instruments was well suited to this task and the data obtained have augmented our understanding of supernova remnants themselves, their interaction with the nearby interstellar medium, and the evolution of the Galaxy as well as the physical processes that are important both in very rarified, hot plasmas and the environment of magnetised neutron stars.

A star is formed by the gravitational collapse of an interstellar gas cloud. Stars are in fact very stable objects that are the result of a balance between the force of gravity and thermal pressure. Since stars radiate a great deal of thermal energy, there must be a source of heat within the star. Depending upon the mass and age of the star, this source of heat is either nuclear fusion or gravitational contraction.

For our star, the Sun, the source of heat at present is the fusion of the fuel hydrogen into helium. For other stars, other nuclear reactions may dominate, depending upon their mass and age, but inevitably the available fuel is used up and the heat source disappears. At that time a dynamic change must occur, involving contraction and heating of the star's core, which in turn may lead to other reactions and a new equilibrium. Eventually everything that can be burnt has been burnt and no significant nuclear heat source is left. At that point most stars simply cool down forever, becoming black dwarfs. The repulsive forces between atomic particles prevent a complete collapse to a black hole.

For some stars, however, the end is more dramatic.

Exploding stars are called supernovae. Supernovae are very bright, about 10 000 000 000 times brighter than the Sun, and for a while a supernova may outshine the rest of its parent galaxy. Astronomers have classified supernovae into a number of types, based on the make-up of their visible spectrum and variations in their brightness. Of these, the most important are Types I and II which are believed to be caused by the following two general scenarios:

Type-I supernovae

Stars usually form in groups and sometimes two stars will be formed such that they are in a relatively close orbit about one another. These binary stars evolve as individual stars until one or other of the stars enters its so-called 'giant phase' and greatly increases in size, so that material may flow from the giant onto its smaller companion. If the smaller star is a white dwarf (a very compact type of star), it may be forced over the edge of stability and spontaneously burn up and finally explode. After a Type-I supernova event, only a hollow shell remains.

Exosat capabilities for studying supernova remnants

In another article in this issue (pp. 65–69), Dr. N. White describes Exosat and its data archive. With regard to the study of supernova remnants, Exosat provided the following features:

- High, non-imaging sensitivity over the range 1.5 – 20 keV with modest energy resolution from the Medium-Energy experiment (ME).
- Medium, non-imaging sensitivity over the range 2 – 20 keV with good energy resolution from the Gas Scintillation Proportional Counter (GSPC).
- Imaging capabilities with modest spectral resolution in the range 0.5 – 2.0 keV from the Position-Sensitive Detector and the low-energy telescopes (LE-PSD).
- Imaging capabilities with some spectral discrimination through transmission filters in the range 0.6 – 2 keV from the Low-Energy telescopes (LE).
- High-resolution timing capabilities from the ME experiment.

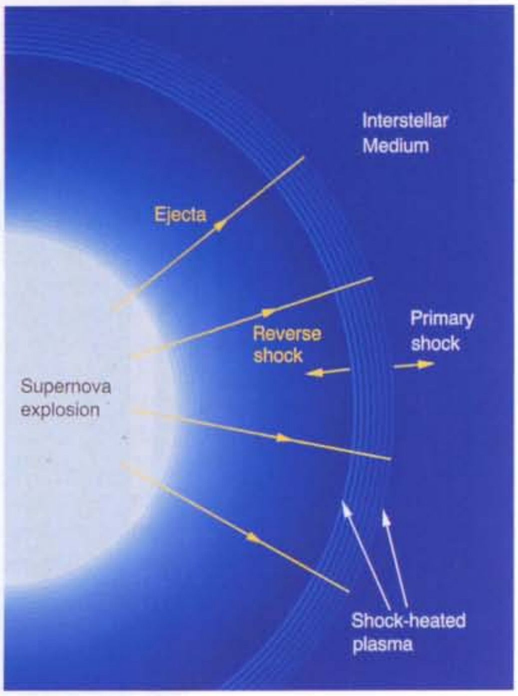


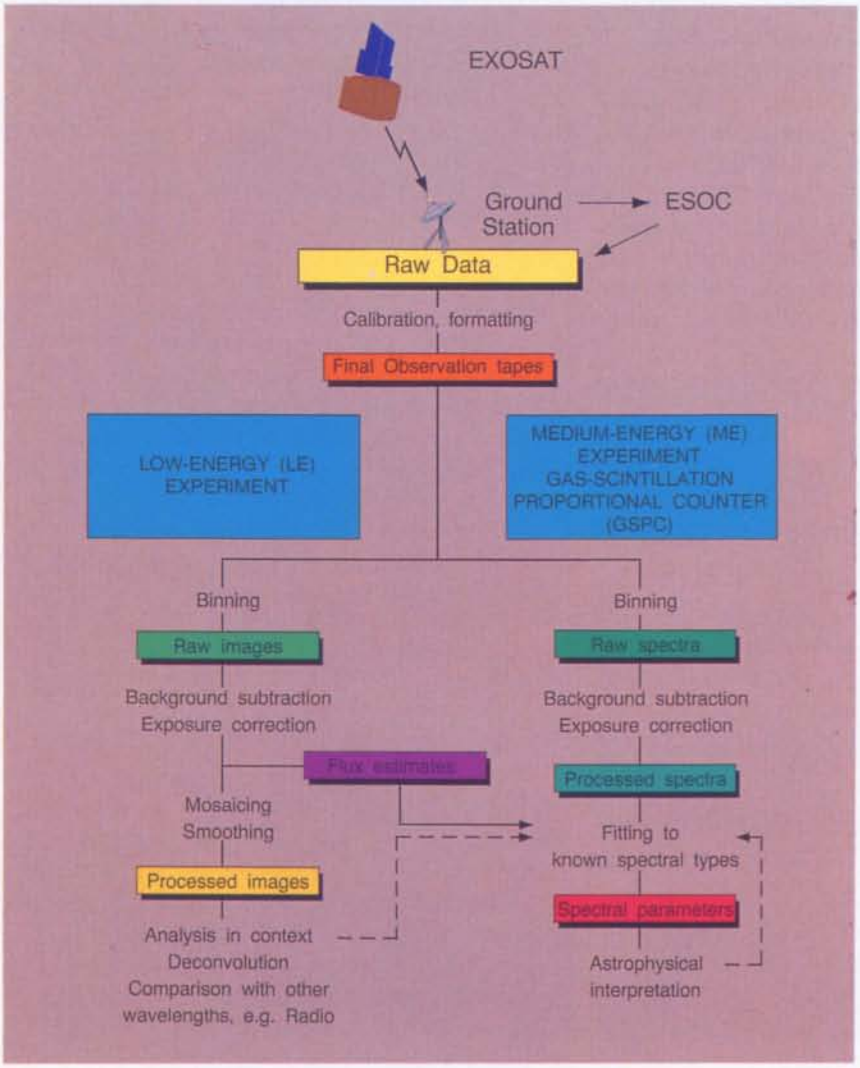
Figure 1. A shell-like supernova remnant

Type-II supernovae

Perhaps surprisingly, massive stars have relatively short, spectacular lives. An unstable condition can develop within the core of a massive star that leads to a catastrophic drop in core pressure. This causes the surrounding stellar envelope to fall in. As the gravitational potential is converted to thermal energy, the star is heated (just as in a waterfall, in which the water is a little warmer at the bottom than the top). The resulting rise in temperature is so large that explosive nuclear burning occurs and the stellar envelope is ejected at velocities greater than 10 000 km/s. It is widely believed that the very dense collapsed core may eventually become either a neutron star or black hole.

Unless you happen to be in the immediate vicinity, supernovae are a good thing. The elements produced during the lifetime of the star and during the explosion are redistributed within the parent galaxy and so become available for new stars and planets. Almost all atomic nuclei, apart from hydrogen and helium, in everything around us (including ourselves) were created in stars in the distant past.

Figure 2. Typical Exosat data analysis procedures



Supernova remnants

During a supernova event a shell of gas is blown off with enormous velocity. This is usually referred to as the ejecta. In studying Supernova Remnants (SNRs) we are concerned with the fate of the ejecta, the compact remnants and their effects on the Interstellar Medium. Supernova remnants are classified into two very broad categories, which are probably related to the two main classes of supernovae themselves.

Shell-like supernova remnants

'Shell-like' supernova remnants are probably most often associated with Type-I supernovae, although in principle all supernovae should produce a shell-like structure. In this case the appearance is dominated by the 'ejecta' or the subsequent disturbances in the Interstellar Medium. When the star explodes all that is left is the ejecta in a loose but expanding sphere. Eventually the expansion starts to slow down as a result of momentum transfer to the local Interstellar Medium and this causes two shock waves to develop (Fig. 1). One, the primary shock, occurs near the outer limits of the sphere of ejecta and soon pulls ahead of it. The other, the reverse shock, travels inwards. Both shocks heat the material, either Interstellar Medium or ejecta, to X-ray emitting temperatures.

Cosmic-ray electrons interact with the compressed magnetic field behind the primary shock to produce synchrotron radio emission. Much later, the velocity of the shock falls below that of typical inter-cloud velocities in the Interstellar Medium and, after about 100 000 years, the remnant fades away.

For the first thousand years or so of a shell-like remnant's life, the effect of both the primary and reverse shocks may be apparent and thermally produced X-rays originating in the ejecta and the Interstellar Medium are combined in the overall spectrum of the remnant. Separating the components and determining the present condition and history of such remnants were among the challenges that faced those interpreting the Exosat data.

Supernova remnants and Exosat results
Although the Cassiopia A (Cas A) SNR is probably not the result of a typical Type-I supernova, it is both shell-like and a thermal X-ray source. It has the advantage that it is relatively bright in X-ray terms and therefore easy to study. Exosat observed it several times during the early part of the mission when the Low-Energy Position Sensitive Detector (LE-PSD) was operational. This gave spectrally resolved morphological data that suggested the presence of a hard outer ring, possibly the shock-heated ISM.

The study of Cas A was augmented by the simultaneous use of data from all the Exosat instruments (Fig. 3). An earlier satellite had indicated the presence of a very high-temperature component in the spectrum of Cas A and this placed significant constraints on the mathematical models of young remnants. The Exosat Medium-Energy (ME) experiment identified an upper limit to this component below the earlier observed value. This Exosat finding has since been supported by results from the Japanese Tenma satellite. This may mean that electrons and ions heated by the passage of the primary shock rapidly reach a thermal equilibrium.

Tycho's supernova remnant is another relatively bright X-ray source that was very well studied by Exosat. Its data was analysed in a number of ways. One analysis was based on the assumption that the hot continuum comes from the shocked Interstellar Medium, as is indicated in the Cas A result. Given this and the known size and distance of the object, its age and expected emitted X-ray line strengths can be calculated. The age derived was 512 years. This compares quite well with the 412 years since the original supernova was observed

X-ray radiation mechanisms

Optically thin thermal plasma emission
Emission from a very hot, rarefied, highly ionised gas. Atoms have all, or almost all, of their electrons stripped due to high-velocity collisions. Continuum emission comes from the interactions between free electrons and atoms while electronic transitions within highly ionised atoms lead to line radiation. Temperatures are typically above one million degrees Centigrade. This type of emission is characteristic of shell-like remnants.

Synchrotron emission
Very energetic electrons spiralling in a strong magnetic field produce synchrotron radiation over a range of energies. Near magnetised neutron stars at the centre of Crab-like supernova remnants, X-ray synchrotron radiation can be produced. Synchrotron radiation spectra are featureless continua.

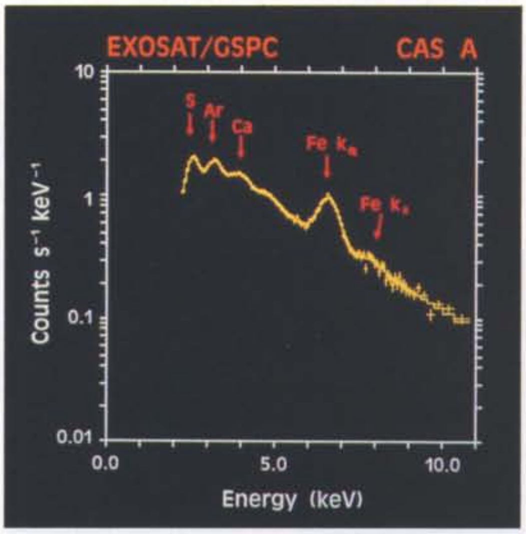
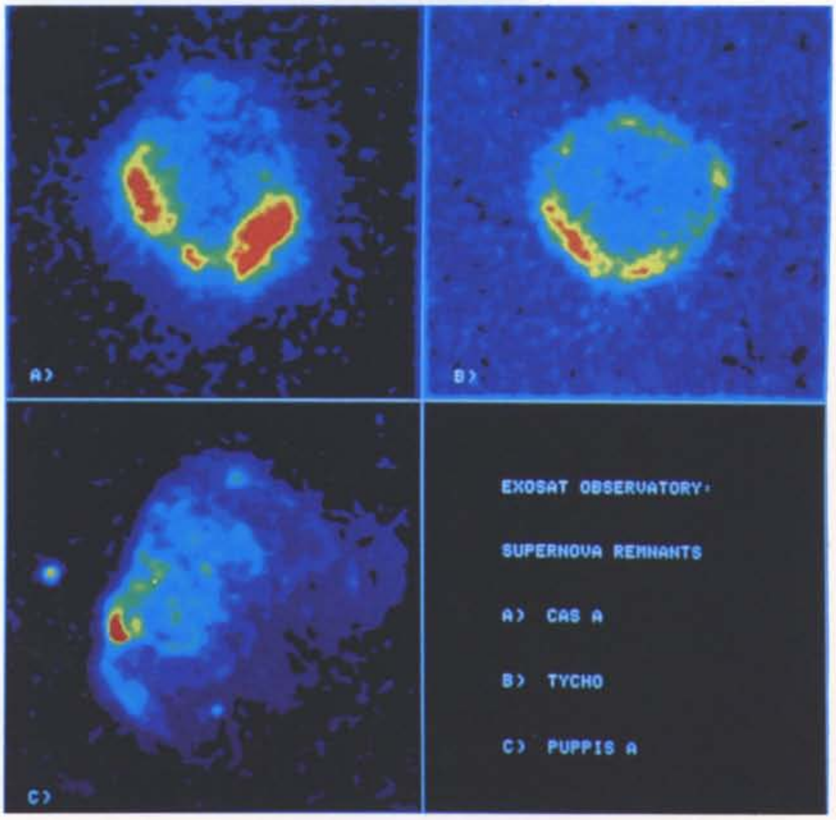


Figure 3. The X-ray spectrum of the SNR Cas A as measured by the GSPC instrument onboard Exosat. Emission lines are due to sulphur, argon, calcium and iron.

Figure 4. The shell-like supernova remnants Cas A, Tycho and Puppis A as observed by the LE experiment on board Exosat. Note the clumpy appearance of Cas A compared with the more ring-like Tycho. The older remnant Puppis A shows the effects of a non-uniform Interstellar Medium



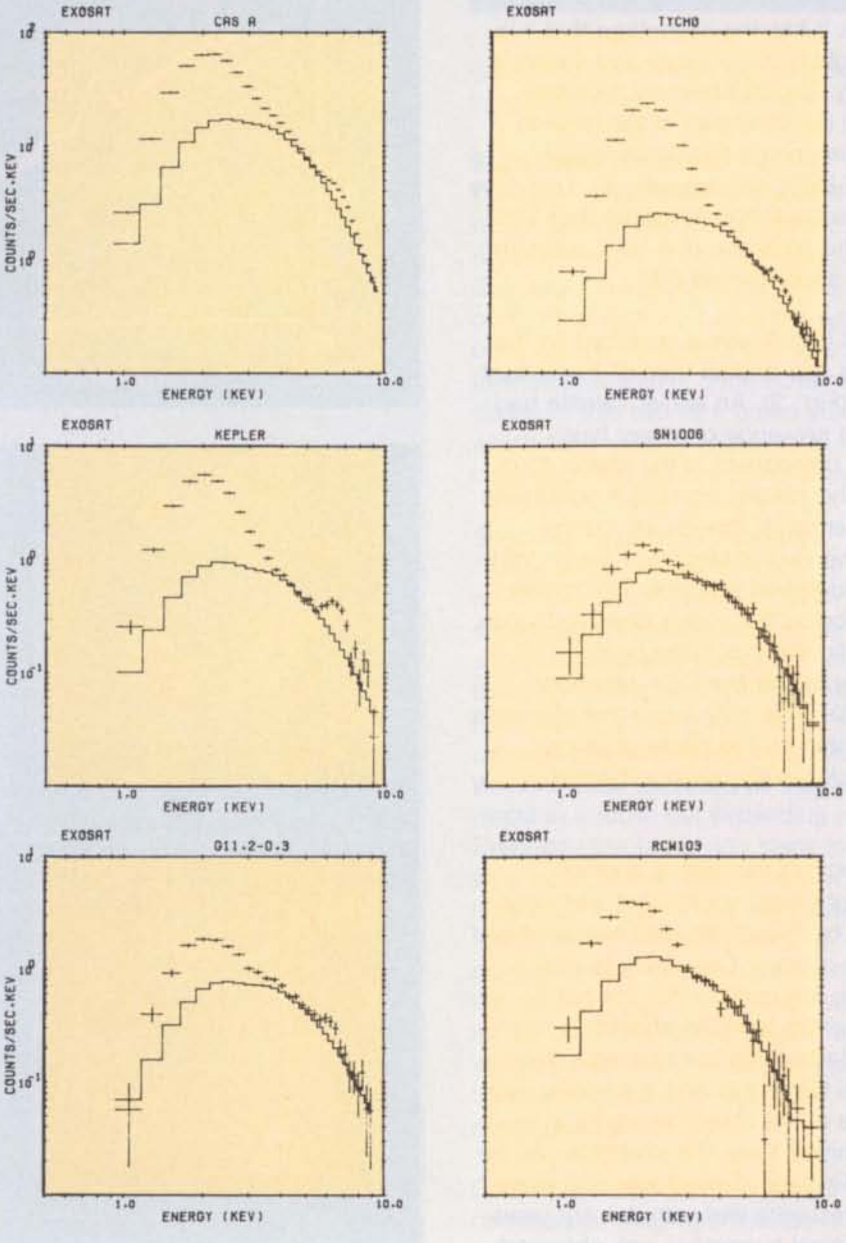
by Tycho Brahe in 1572. The observed line emission for silicon and sulphur was far greater than expected.

The results from the LE telescope (Fig. 4) were critical in this analysis, since much of the line emission originates at low energies, not seen by the ME or Gas-Scintillation Proportional Counter (GSPC) experiments. The conclusion is that while the hot continuum comes from the ISM, the very strong line emission comes from the interior, reverse-shock heated ejecta. The emission due to iron may come from both.

Another approach was to compare the observed GSPC spectrum with computer predictions from a model running on a Cray computer at the Max-Planck Institut für Extraterrestrische Physik in Garching, Germany. This model assumed the explosion of a white dwarf and calculated the expected emissions after 412 years. After each run the model was refined, rather like changing the relative ingredients of a cake mix, and the 'cake' was baked again. Eventually a reasonable fit was achieved which suggested that the expanding ejecta did not maintain a cohesive sphere, but that some 'mixing' occurred. This had not previously been foreseen. Earlier models of the Type-I supernova explosions usually assumed that the ejecta retained its relative composition structure as it was blown off.

Several other similar remnants were studied by Exosat including, Kepler's SNR, SN 1006, RCW 86 and RCW 103 (Fig. 5). In all cases

Figure 5. The spectra of six shell-like supernova remnants as measured by the ME experiment onboard Exosat (crosses). The solid line is the best-fit thermal continuum. The excesses seen at the left and, to a smaller extent, near the middle, are due to line emission from silicon, sulphur and iron



a good estimate could be made of both the continuum temperature and iron emission line strength. In all cases the assumption that these components originated in the Interstellar Medium seems consistent with the observations, since the ages derived are similar to those of the observed explosion.

In the case of Kepler's SNR, very strong iron line emission was observed and is naturally explained by this assumption. Likewise the absence of any line emission seen in the spectrum of SN 1006 is explained by its location in a very low density part of the Interstellar Medium. The strongest iron emission feature for any supernova remnant was discovered in the W 49B remnant which, like W 44, is centrally peaked rather than shell-like.

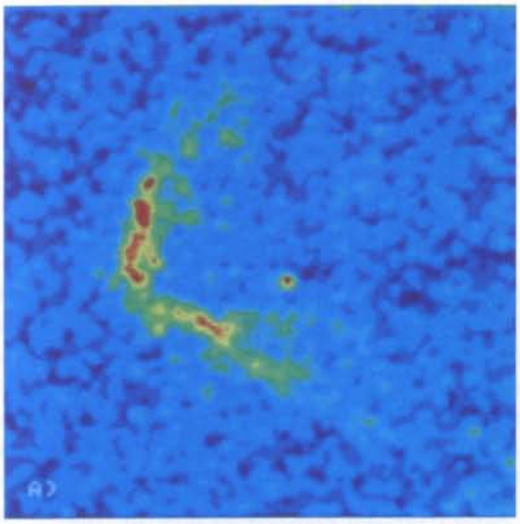


Figure 6. The smoothed image of SNR RCW 86 showing two distinctly different radii of curvature associated with different Interstellar Medium densities. The bright spot near the centre of the image is an instrumental artifact

The remnant RCW 86 was large enough to be mapped by the 45 arcminute field-of-view of the Medium-Energy experiment (Fig. 6). This object is probably related to SN 185 and so is about 1800 years old (supernova numbers refer to years AD) and probably entering 'middle-age'. This is reflected in its asymmetric appearance, in which different parts are seen to be at different stages of evolution, due to the differing structure and density of its local Interstellar Medium.

In older supernova remnants the situation is perhaps simpler, although in these cases the shape of the remnant may have been significantly affected by varying densities and even massive molecular clouds in the Interstellar Medium. Exosat observed a few of these objects. Only relatively nearby ones could be observed because they tend to be very 'soft' (i.e. emit at longer X-ray wavelengths) and are attenuated by interstellar absorption in the galactic plane. This also makes them very large compared with the field-of-view of the instruments. The Vela remnant proved to be too large for a complete mapping, but mosaicing of the most important parts from many observations was possible.

The SNR Puppis A has a smaller angular diameter and was completely covered. Figure 4 shows a beautiful example of the effects of an unseen non-homogeneous Interstellar Medium on the spherically symmetric blast wave. Note the very strong emission in the top left of the image. The contours are radio measurements of a molecular cloud that the remnant has clearly run into. The emission from these objects is also complicated by the superposition of multiple components. In the case of Puppis A, changes on the scale of 1 arcmin are observed, which are related to the effects of different shock-heated Interstellar-Medium clouds.

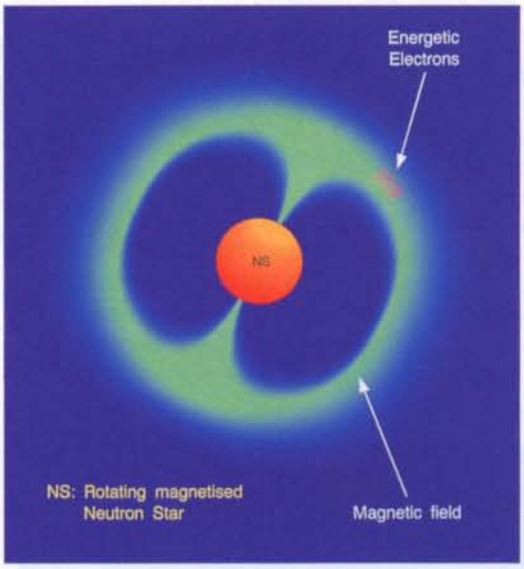


Figure 7. A crab-like supernova remnant

Crab-like supernova remnants

'Crab-like' supernova remnants are probably related to Type-II supernovae. A spinning neutron star with a very strong magnetic field is left at the centre of the explosion (Fig. 7). The power from the slowing-down of the neutron star's rotation dominates the appearance and dynamics of the remnant and, although a classical component is still expected, it is quite often completely overshadowed. The neutron star is observed inside a nebula where very energetic particles and very intense magnetic fields are present. This combination leads to synchrotron radiation that can be detected over a wide range of the electromagnetic spectrum (radio to X-ray). The spectrum from the nebula is characteristically featureless. These synchrotron nebulae are relatively short-lived (10–20 000 years) as the neutron star slows down and eventually becomes a radio pulsar.

Crab-like supernova remnants are named after the most important member of the group, the Crab Nebula. The Crab Nebula was probably the most important target ever observed by Exosat (Fig. 8). This object has been extensively observed by other satellites and rocket-borne experiments and has a simple, featureless spectrum that makes it ideal as a standard. It was therefore used as a basis for the in-flight calibration of the Exosat instruments.

The spectra from a number of Crab-like remnants were obtained by Exosat with a greater precision than had ever been achieved before. Interestingly, the spectral indices, or slopes, were all similar, although not the same. This indicated that, whereas the mechanism that created the energetic electrons was probably shock heating, other processes that depend upon the situation within each remnant must be involved at a secondary level. The expected index for pure shock heating is 2.0, whereas indices in the range 1.7 to 2.3 were observed.

After the re-entry of Exosat, two supernova remnants were discovered to contain fast radio pulsars. These objects were CTB 80 and W 44. Both were unusual objects in their own right. In both cases the Exosat results were re-examined to seek pulsed X-ray emission. Although none was found, useful upper limits were obtained which indicated that certain emission processes that might be responsible for the X-ray emission seen in other remnants could not apply to these. In the case of CTB 80 the spectral index previously published (3.8), based on observations with another satellite, was found to be in error and a value of 1.9 was measured, just right for a Crab-like remnant. W44 remains more of an enigma since although it has a central pulsar, it has a centrally bright (i.e. not shell-like) thermal spectrum.

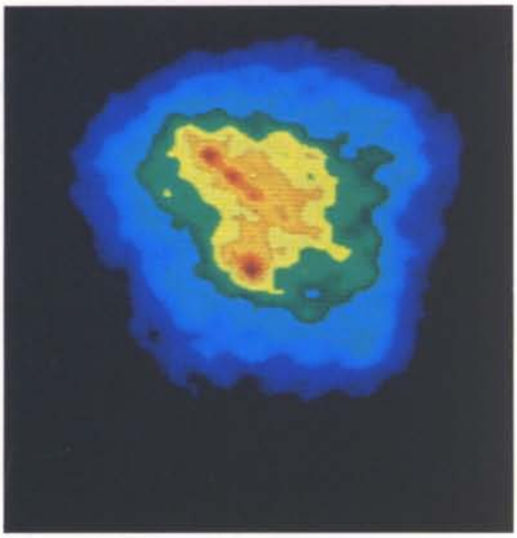


Figure 8. The Crab nebula as observed by Exosat. Note the filled centre morphology

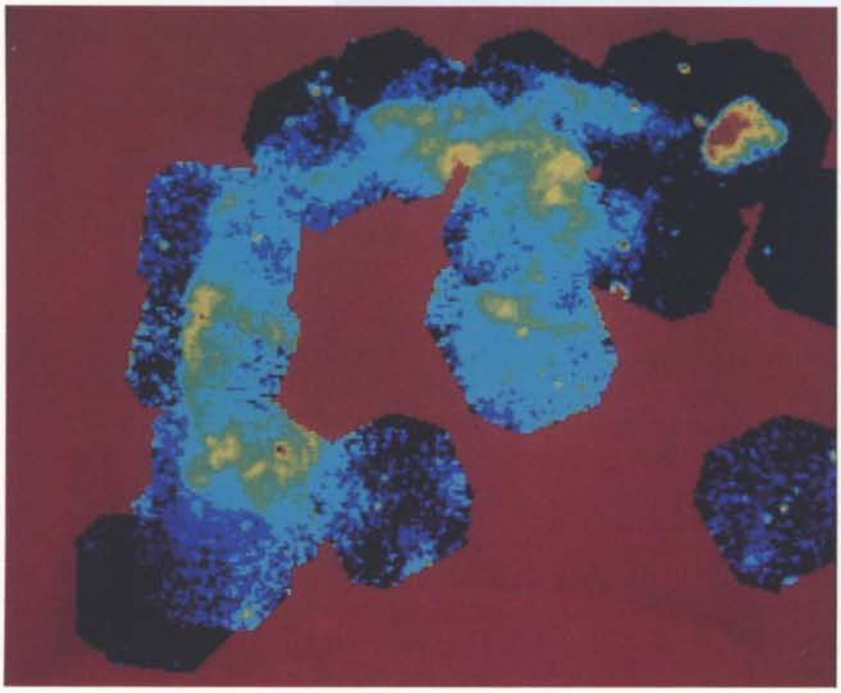


Figure 9. A smoothed mosaic of the brightest parts of the Vela SNR. The bright spot near the centre is associated with the radio pulsar PSR0833-45, believed to be the neutron star at the centre of a Crab-like component (not seen in this plate). The width of the image is approximately 8°. The blank red areas are those parts of the sky not observed by Exosat

The Vela supernova remnant contains an older Crab-like component (Fig. 9). The Medium-Energy detector was used in a multi-pointing mode to map the extent of the X-ray emission, which was found to be extended on the scale of a degree (twice the angular size of the full moon) although it was not seen so extended by the Low-Energy telescopes, probably because of the differing spectral responses.

Conclusion

Exosat made many useful studies of supernova remnants but, like most successful experiments, has raised more questions than it answered. To proceed further we require higher spatial and spectral resolution and greater sensitivity, all of which will be provided by ESA's High-Throughput Astrophysics Mission, XMM, due for launch in 1998.

The Exosat Database System

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Exosat was the first of ESA's scientific satellites to receive funding for a post-operational phase to support the scientific community wishing to exploit its archival data. A major part of this activity has been the development of an online database containing standard data products and results from the mission. This database and its associated operating system provide astronomers with a powerful new tool for efficiently accessing and analysing large volumes of data.

Introduction

The European Space Agency's X-ray observatory Exosat was operational from May 1983 to April 1986 and made 1780 detailed observations of a wide variety of objects including active galactic nuclei, stellar coronae, cataclysmic variables, white dwarfs, X-ray binaries, clusters of galaxies and supernova remnants (see pages 59–64 of this issue). The payload complement consisted of a large-area proportional array, two imaging telescopes (each with a transmission grating spectrometer), and a gas-scintillation proportional counter (Table 1). A unique and highly successful aspect of the mission was the eccentric 90 h orbit of Exosat which, for the first time, gave the capability to make uninterrupted observations of the time variability of X-ray sources for several days at a time.

Table 1 — The Exosat instruments, their scientific groups and principal contractors

Element	Institutes	Contractors
Low-Energy Imaging Telescopes (LE)		
Optics	SRON, Leiden (NL)	CIT-Alcatel (F), Instruments SA (F), Fichou (F)
Detectors	MSSL, London (UK)	Sira (UK)
System/Electronics		Matra (F), SNIAS (F), Laben (I)
Gratings, Filters	SRON, Utrecht (NL)	
Medium Energy Experiment (ME)		
System and detectors	Univ. Leicester (UK) MPE Garching and Univ. Tubingen (D)	BAe (UK), LND (US) Galileo EOC (US)
Electronics		Laben (I), Matra (F)
Gas Scintillation Proportional Counter (GSPC)		
Detector and System	SSD, ESTEC MSSL, London (UK) Univ. Palermo and LFCTR, Milan (I)	AEG (D), Electrofusion (US) Laben (I)

The Exosat science operations were analogous to the operation of a ground-based telescope. Observation time was assigned on a competitive basis, with an observatory team established to support the scientific operations at the Agency's European Space Operations Centre (ESOC) in Darmstadt, Germany. The proprietory data rights of a principal investigator were restricted to the first year after data receipt and, by the end of 1987, the entire Exosat data archive was open to the astronomical community.

Exosat received funding for a four-year post-operational phase (January 1987 – December 1990) to maintain the infrastructure, equipment and scientific personnel for the proper support of the scientific community wishing to exploit the satellite's data archive. At the end of operations the Exosat observatory team of 13 astronomers was moved from ESOC to be co-located with the ESA Space Science Department at ESTEC for the duration of the post-operations phase.

The Exosat database system utilises the recent expansion in the computer networks and advances in database-management techniques to provide on-line access to Exosat data products and results. World-wide access is provided by the Space Physics Analysis Network (SPAN), Internet (TCP/IP) and PTT X.25 connections (see Bulletin no. 61, pp. 65–69). Ultimately the Exosat database will become a node within the European Space Information System, ESIS.

A data archive infrastructure

The Exosat mission produced a total of 150 Gbytes of data (currently residing on 6000 magnetic tapes at ESOC). Figure 1 shows the number of data tapes requested from the archive per year. As the data became freely available in 1986–1987, there was a surge in requests resulting in the dispatch of 600 final observation tapes in 1987 (or 10% of the entire archive). This settled down to a steady rate of 350 tapes per year in 1988 and 1989.

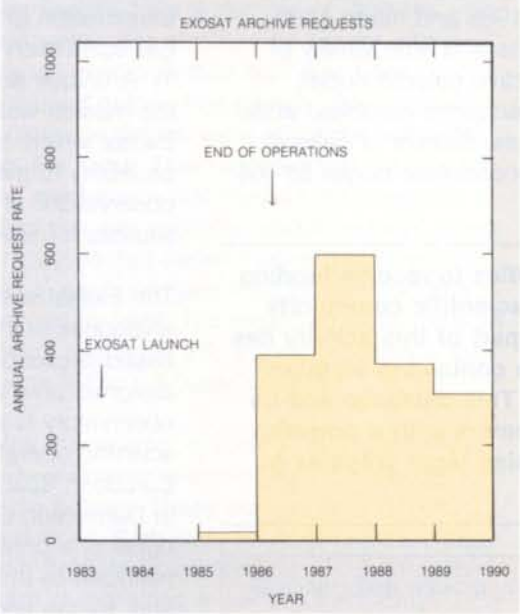
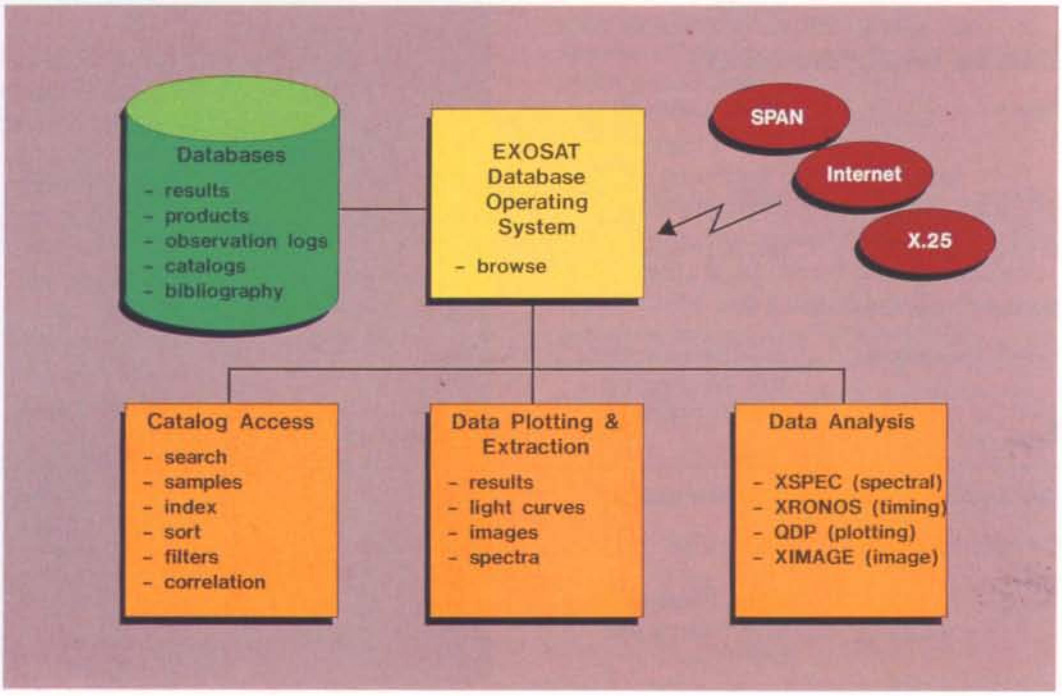


Figure 1. The number of final observation tapes requested per year from the Exosat data archive. The arrows indicate when the archive opened and the end of operations. There are 6000 tapes in total.

The reduction of these raw data tapes into data products (i.e. images, light curves and spectra) is complex because of the sophisticated nature of the instruments and onboard data-compression techniques. Extensive analysis software, and expertise in the nuances of the instrumentation, is required to obtain high-quality data products and results. While several groups in Europe, mostly those associated with the Exosat instrumentation, have made such an effort, many others do not have the required resources.

The complex nature of the Exosat data analysis acts as a barrier to archival research. Past experience with similarly complex astrophysics missions had shown that, after only a few years, the data became inaccessible as the expert personnel moved on to new projects. A high priority of the Exosat post-operational phase was to establish an archival infrastructure to ensure long-term accessibility to the data archive.

Many of the required data-processing tasks are repetitious and amenable to automisation. A number of standard data products (light curves, images and spectra) and results (count rates, source positions, etc.) were defined for the Exosat mission and then generated by running the Exosat analysis software in an automatic mode. The Exosat database system is designed to allow non-experts with only a rudimentary knowledge of the satellite's instruments, e.g. a theoretician, to gain immediate access to these data products.



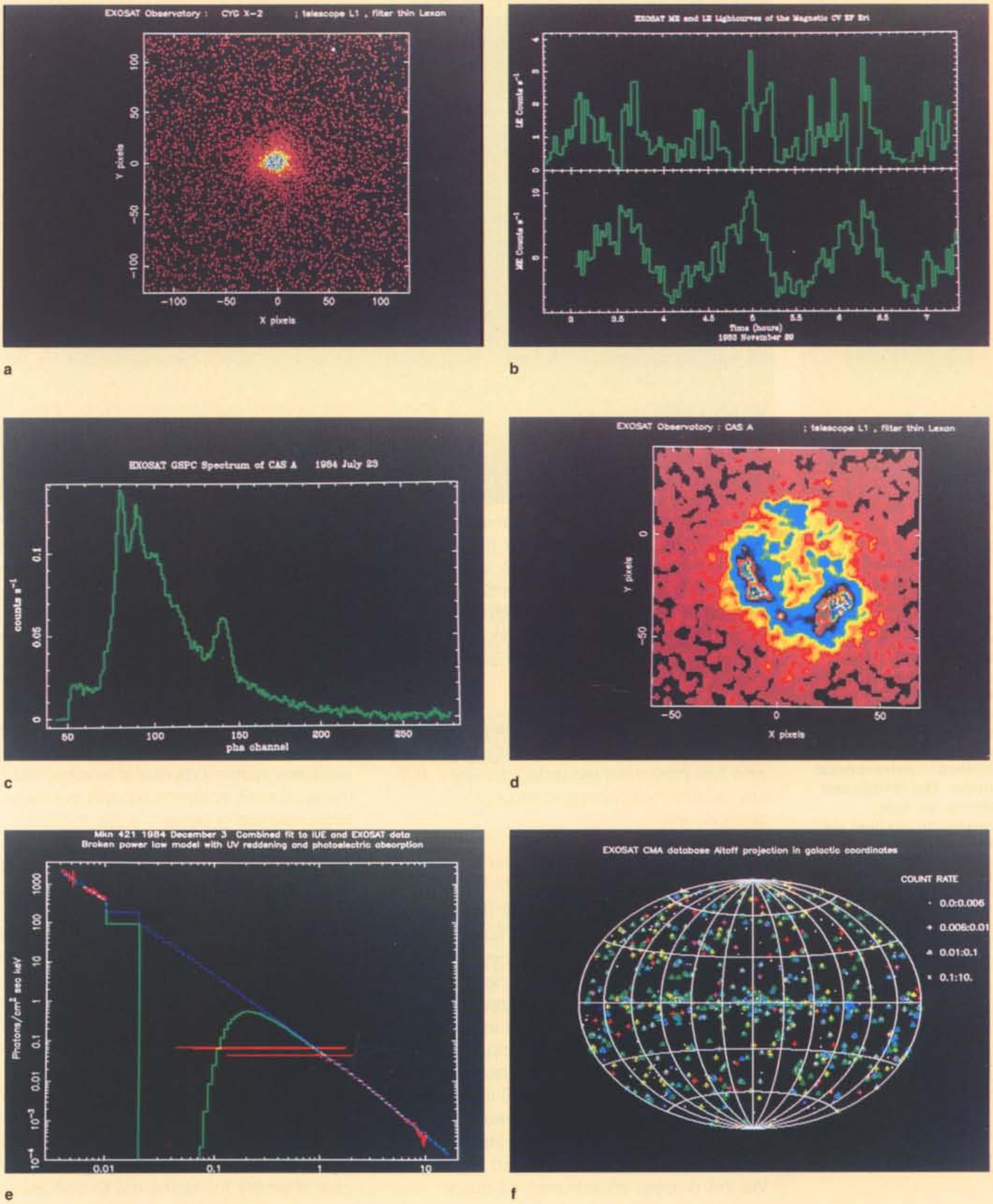


Figure 2 a-f. A selection of data products available through the Exosat database system. a) An image of the accreting neutron star Cygnus X-2 taken with the low-energy imaging telescope. b) A light curve of the magnetic cataclysmic variable EF Eri, taken by the low- and medium-energy detectors. c) A GSPC spectrum of the supernova remnant Cas A. d) A smoothed image of Cas A. e) The IUE and Exosat spectrum of the active galactic nuclei MKN 421. f) All the sources detected by the low-energy imaging telescopes, with different symbols used to denote different brightnesses.

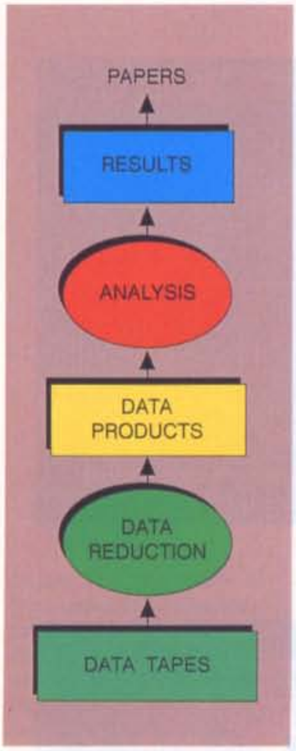


Figure 3. The flow of the automatic processing used to generate the contents of the Exosat database. The 6000 'data tapes' undergo 'data reduction' to produce 'data products' (light curves, spectra and images). These in turn are analysed by 'analysis programs' to produce 'results' which can then be published in astronomical journals. The results and products are kept permanently 'on-line' via the Exosat database.

The available data products are limited by the amount of magnetic disk space. When complete, at the end of 1990, they will occupy 5 Gigabytes and will mostly consist of low-time-resolution spectra, light curves and images, plus high-resolution light curves from a selection of objects. It is obviously impossible to anticipate every data product that will be required and, in some cases, an astronomer must still request and analyse the raw data tapes. This is expected to be true in 20–30% of the cases, but even then the Exosat database is invaluable in establishing the available observations and overall source characteristics. The astronomer can therefore minimise the analysis of the raw data and hence the time spent at institutes with a full Exosat analysis system. It is also possible to request the raw data electronically using the Exosat database.

Data products and catalogues of results from other related observatories are also available through the Exosat database. These include data from NASA's Einstein observatory, the International Ultraviolet Explorer (IUE) and various astronomical catalogues, e.g. the Hubble Space Telescope Guide Star Catalogue. These related data are essential for making correlated studies, source identification, and long-term variability studies.

To avoid duplication of effort, there is a 'data history' including who made the observation, who has previously requested the data, and any publications relating to those observations.

The user interface

The user interface to the Exosat database system is a command-driven environment optimised for astronomical queries that allows astronomers, both experts and novices, to 'browse' through the available data, and select those required. This user interface was developed with the active participation of the astronomical community. Two 'database workshops' were held at ESTEC in December 1988 and February 1990 to demonstrate the system and obtain feedback to improve it. Forty astronomers attended each workshop. Via this process an astronomical-query language, optimised for both browsing through the database and for remote access, has been developed.

Graphics is an important element that allows the display of plots directly over the networks. Figures 2a–f show plots of images, light curves and spectra from the Exosat database system. This on-line graphics capability allows the astronomer to display the results and data products directly. All popular graphics devices are supported. In addition, Postscript files can be produced and electronically mailed back to the user, giving publication-quality output.

Extraction of the data products and their transfer over the networks is also possible. These analysis programs can either be run by remote log-in, or they can be installed on the user's computer by the Exosat observatory staff.

A database management system (DBMS) is used to locate the results and data products. It has been written by members of the Exosat observatory team and is optimised for astronomical queries. Here the emphasis is on correlation analysis between large tables of parameters that are rarely changed (e.g. a catalogue of stars). The Exosat database operating system has been specifically written in a mission- (and wavelength-) independent fashion and can be applied to other astrophysics missions.

The Exosat database provides a direct interface between the data products and the analysis software. This allows a remote user to analyse thousands of data products, selected using the DBMS. These products can be further selected based on the results of this analysis. In this way, the Exosat database system provides a powerful tool for the systematic analysis and interpretation of large volumes of data.

The Exosat database system was made available for remote use in April 1989. In the first year there was a total of 182 users and 3261 sessions. Figure 4 shows the number of users per week. Currently there are typically 5–10 remote users per day, with an average of 100 sessions per week.

The future

The Exosat database system has applied database-management technology to data analysis in the astrophysics context and in doing so has surpassed the original design goal of simply managing the Exosat data products and results. It is the first of a new generation of data-analysis system optimised for large data volumes and network access. Externally defined data structures specify the underlying binary data so that virtually any data format can be incorporated, without any major changes to the underlying software. This will allow the analysis of data from many

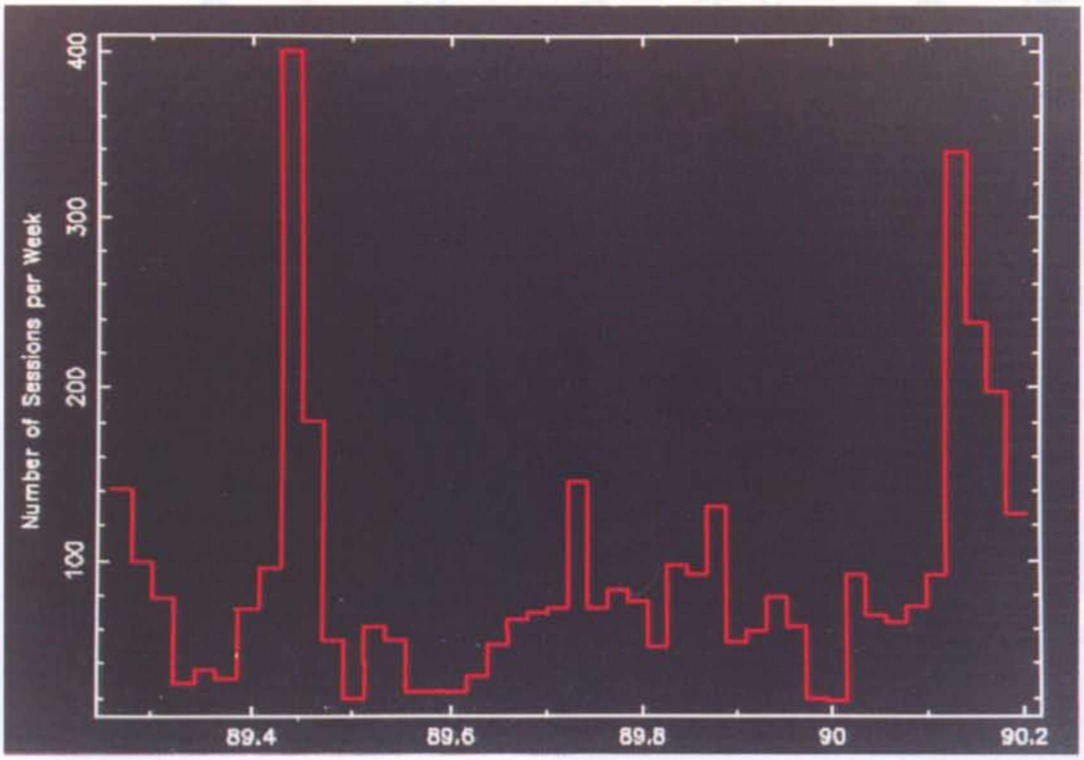


Figure 4. The usage of Exosat data April 1989 – early 1990. It plots the number of remote sessions per week. The two peaks are database workshops, where the system was demonstrated to and used by astronomers.

different missions within a single analysis environment. Indexing of the raw data on any constituent parameter will give much faster data access than the current generation of astrophysics data-analysis systems.

The system will be released in the latter half of 1990 as a package. It will be installed at sites around Europe and the rest of the World, as a complete data-archive/data-analysis system. It is expected that these sites will install a subset of the Exosat data products that are of particular interest to that institute, and make them available for local use. Several institutes are already testing the current prototype Exosat database system, with a view to its use in their own archiving efforts. These institutes can then incorporate their own data products and results obtained from their own telescopes and also make them available for network access.

Conclusion

It can be anticipated that in the near future astronomers will access vast amounts of astronomical data, both new and archival, thousands of kilometres from where the data have been collected and stored. Such a capability will only be of use if the data are organised in a manner that aids the enquiring astronomer rapidly to search, filter and display catalogues, data products and raw data based on any combination of parameters. The Exosat database system provides such an infrastructure.

EXOSAT resides on a VAX cluster at ESTEC in the Netherlands and is available to users on a 24 hour basis. The cluster is accessible for interactive logins via the following methods:

SPAN:
NODE NAME: EXOSAT
NODE NUMBER: 28703
DEC Example:

```
$ SET HOST EXOSAT
$ SET HOST 28703
```

ARPAnet/INTERnet/PSI:
Users must first register by sending their TELNET/PSI address with
28703::request
After connecting with one of the above methods, the ESTEC VAX will signal its presence and the user will be prompted to enter a USERNAME Enter XRAY at the USERNAME prompt and proceed, no password is required

The Consultative Committee for Space Data Systems (CCSDS): Its Achievements and Their Significance for ESA

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The Netherlands

In 1982 many of the World's space agencies met to discuss common problems relating to space information and data systems. It had long been realised that the growing complexity of space missions, as well as their associated costs, could adversely impact space endeavours in the future, unless specific efforts were undertaken to address these concerns. Accordingly, the Consultative Committee for Space Data Systems (CCSDS) was established to perform end-to-end system analyses and, through the collective efforts of its international experts, to develop advanced solutions to these common problems (Fig. 1).

These solutions, called 'CCSDS Recommendations', are reviewed and officially accepted by the CCSDS Member Agencies before being released as 'Approved Recommendations' ('Blue Books' in CCSDS terminology). Although the participating Agencies are not obliged to adopt these Recommendations, their use not only saves the time and money inherent in one-off systems development, but also provides further collective benefits through the promotion of cross-support opportunities (Fig. 2).

Functioning of the CCSDS

Space agencies have been using standards for data structures since the start of their activities at the beginning of the sixties. Most were adaptations of existing industrial standards and were only used internally; some were taken over from other agencies, and thus a *de facto* inter-agency standardisation was achieved in selected areas, such as in certain types of time-division multiplex telemetry formats. With the growing complexity of space data systems, the problem of diverging systems evolution and standards was growing. Consequently, the space-data-system experts and the managers of a number of space agencies started discussing systematic harmonisation, and this led, eventually, to the foundation of the CCSDS in 1982.

The Committee's objective is to establish recommendations for standards particularly in those areas where inter-operability between the different space agencies is already, or is likely to become, important. Its activities are conducted by four 'Expert Panels', supported by a Secretariat, and coordinated by a Management Council composed of senior representatives of the Member Agencies plus the Panel Chairmen. The Panels and the Management Council meet approximately twice per year (Fig. 3).

Plenary meetings of all Member and Observer Agencies are organised every two to three years to review the work being carried out, to approve Recommendations, and to direct future activities.

Achievements to date

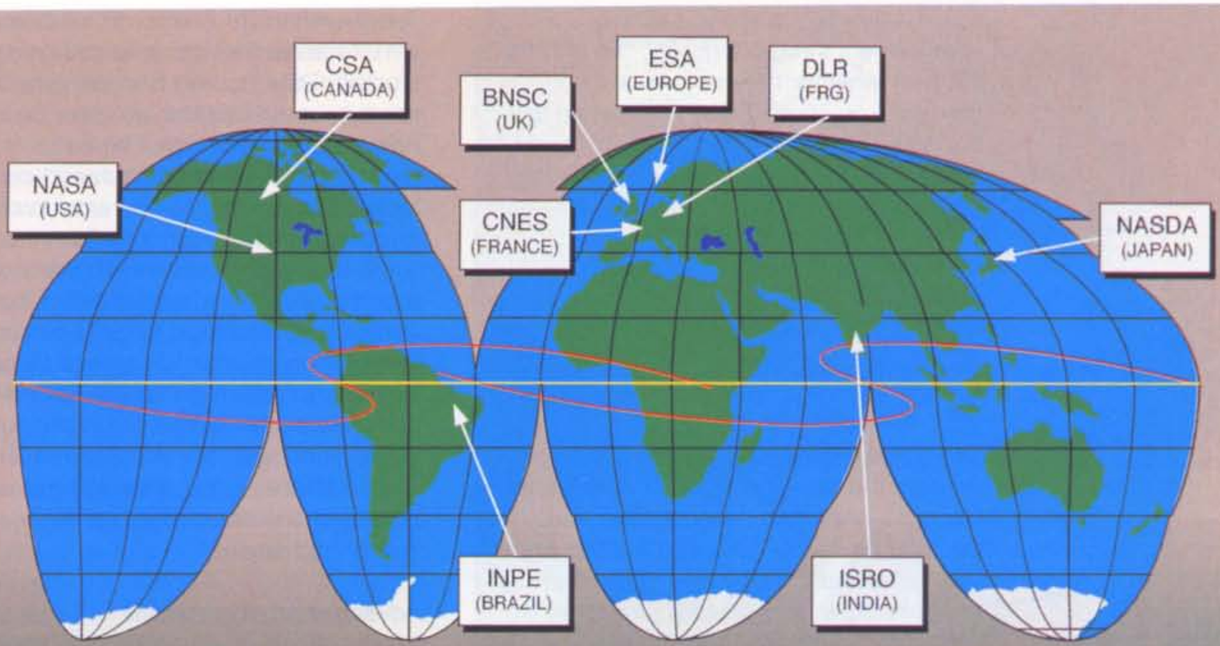
During its eight years of existence, the CCSDS has produced recommendations in the fields of telemetry, telecommand, time coding, RF and modulation, internetworking, standard formatted data units, and radiometric and orbit data.

CCSDS Recommendations related to space-ground-link services

Telemetry

In 1984 the CCSDS approved its first two Recommendations which deal with 'Telemetry Channel Coding' and 'Packet Telemetry'.

The former recommends a small number of high-performance error-correcting codes that are applicable to a large number of space missions. As we progress into modern data-driven processing, data compression, and automated, high-volume ground data handling, data errors are becoming unacceptable and cause many problems that can no longer be fixed 'by hand'. Powerful error-correcting codes are now available

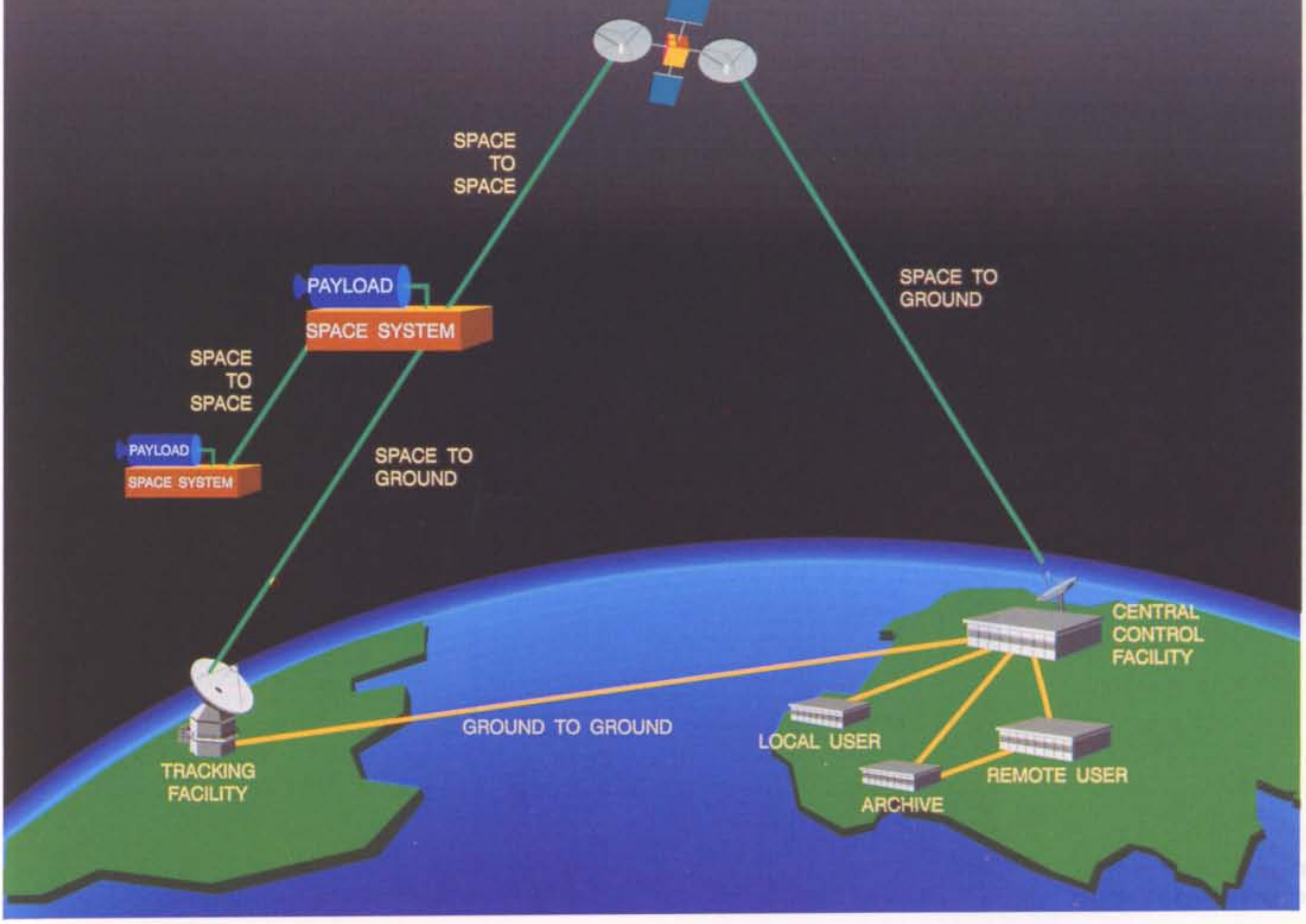


CCSDS OBSERVER AGENCIES

CAST (P.R. CHINA)
CRC (CANADA)
CTA (BRAZIL)
ISAS (JAPAN)
NOAA (USA)
CRL (JAPAN)
SSC (SWEDEN)

Figure 1. The CCSDS Member and Observer Agencies (as of September 1989)

Figure 2. Typical technical data interfaces between Agencies



which not only provide a dramatic improvement in output quality, but also tell the user whether the errors have been corrected or whether they are so bad that the data cannot be corrected and should be eliminated (as opposed to the 'best-guess' error correction used in the past).

By standardising on these few well-engineered codes, project-unique encoding and decoding equipment is minimised and coding services become routine capabilities for inter-agency cross-support.

The 'Packet Telemetry' Recommendations address the standardisation of satellite down-link data, using two principal data structures: the 'Source Packet' and the 'Transfer Frame'. The technique provides the mechanism by which multiple data sources can share a common communications channel. It requires each data source to label its data in a certain way, but does not dictate how the data themselves should be arranged. The message packet is inserted into fixed-length transfer frames which are optimised for high-performance transfer to the ground, where the packets can be easily extracted. The result is that data-transport and ground-processing services become independent of message format and content, and thus become standard services for missions that have adopted these standards.

Figure 4 shows the principal elements of the space-ground-link data structures.

Telecommand

In 1987, the CCSDS released three Telecommand Recommendations dealing with 'Channel Service' (telecommand code blocks), 'Data Routing Service' (telecommand frames), and 'Data Management Service' (telecommand packets). The first recommends synchronisation and coding techniques for correcting a small number of errors and improving the performance of somewhat noisy channels. The second deals with the accounting entities (telecommand frames) that may have to be re-transmitted by one of three specific 'Command Operations Procedures' which are invoked to achieve complete and error-free commanding when errors or outages are encountered. The third deals with the aggregation and management of related command loads for various on-board applications.

Advanced orbiting systems

In view of the growth in important new programmes of an international nature, such as the International Space Station 'Freedom', the CCSDS Recommendations also address expanded telemetry and telecommand structures for advanced orbiting systems. The proposed solutions can usually exploit the built-in flexibility, and do not require radical changes. The additional requirements to be met include: (i) voice dialogue, (ii) the possibility of establishing a connection from both ends, (iii) guaranteeing the completeness of data transmitted in both directions, (iv) automation of the communications management, and (v) inclusion of voice and video data.

The complexity of such systems, however, particularly in the area of internetworking,

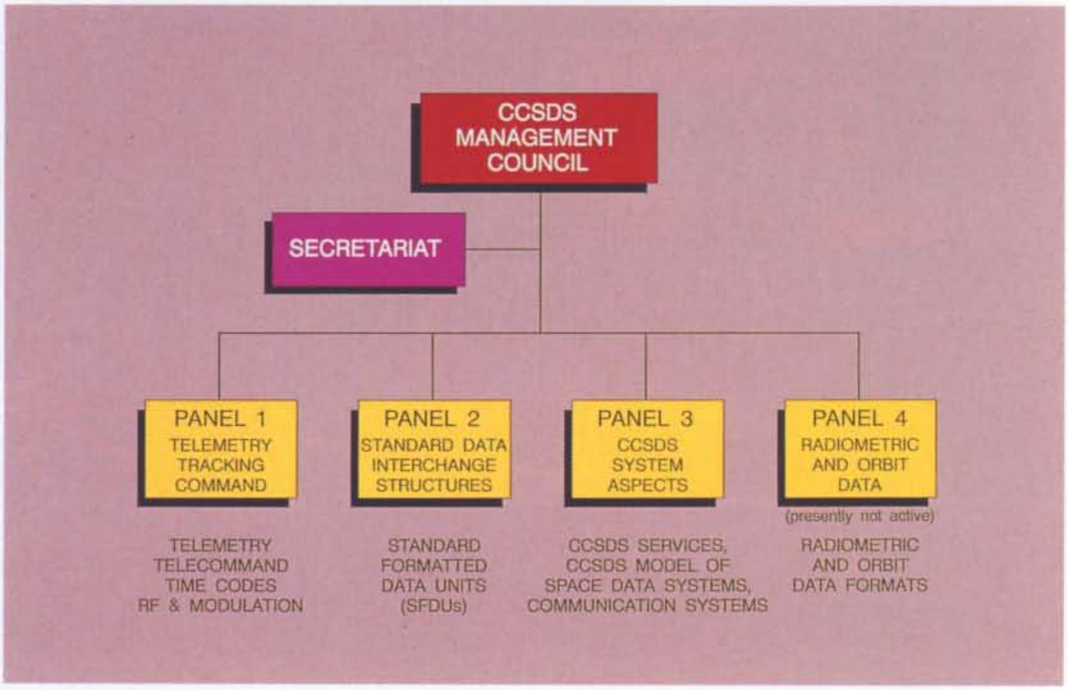


Figure 3. The CCSDS's organisational structure

has meant that the CCSDS has had to extend its traditional scope of interest into both the on-board and ground networks, defining a conceptual model known as the CCSDS Principal Network (CPN). Two internetwork services have been agreed — Path and Internet — which will directly support the routing of data across Agency domains in the on-board, space-link and ground subnetworks, and may also be used as the basis for further agreements on upper-layer protocols. A full suite of services and protocols have also been agreed for the space link, providing full inter-operability within that subnetwork, and supporting a diverse range of data types, including telemetry, telecommand, voice and video.

Time-coding
In elaborating the Telemetry Recommendations, it became necessary to publish Recommendations on the time coding that is normally transmitted with the subsystem and payload information. It was deemed desirable to reduce the large number of different segmented time codes then in use by agreeing on the recommendation of two segmented codes and one un-segmented code.

Radio frequencies and modulation
There is great interest in harmonising the characteristics of ground–space radio links for space applications, which normally represent large investments. As a first step, an inventory of the CCSDS Member Agencies' relevant facilities was established, and their detailed characteristics compiled in the document 'CCSDS Radio Frequency and Modulation Report'. Subsequently some 70 different Recommendations have been agreed to, which are contained in the CCSDS 'Blue Book' titled 'Radio Frequency and Modulation Systems, Part 1: Earth Stations and Spacecraft'. They cover: Earth-to-space radio frequencies, telecommand data modulation, space-to-Earth radio frequencies, telemetry-data modulation, radiometric measurements (tracking), and spacecraft characteristics related to radio frequencies and modulation. This document will be updated as new Recommendations are worked out and future effort will also be devoted to space-to-space links.

Validation of CCSDS Recommendations

In order to ensure the correctness of its Recommendations, the CCSDS endeavours to subject all of its products to vigorous validation and verification schemes. The validation process ensures that the formal specifications are complete and correct, but verification is also necessary to confirm that the original concept and design meet the operational requirement.

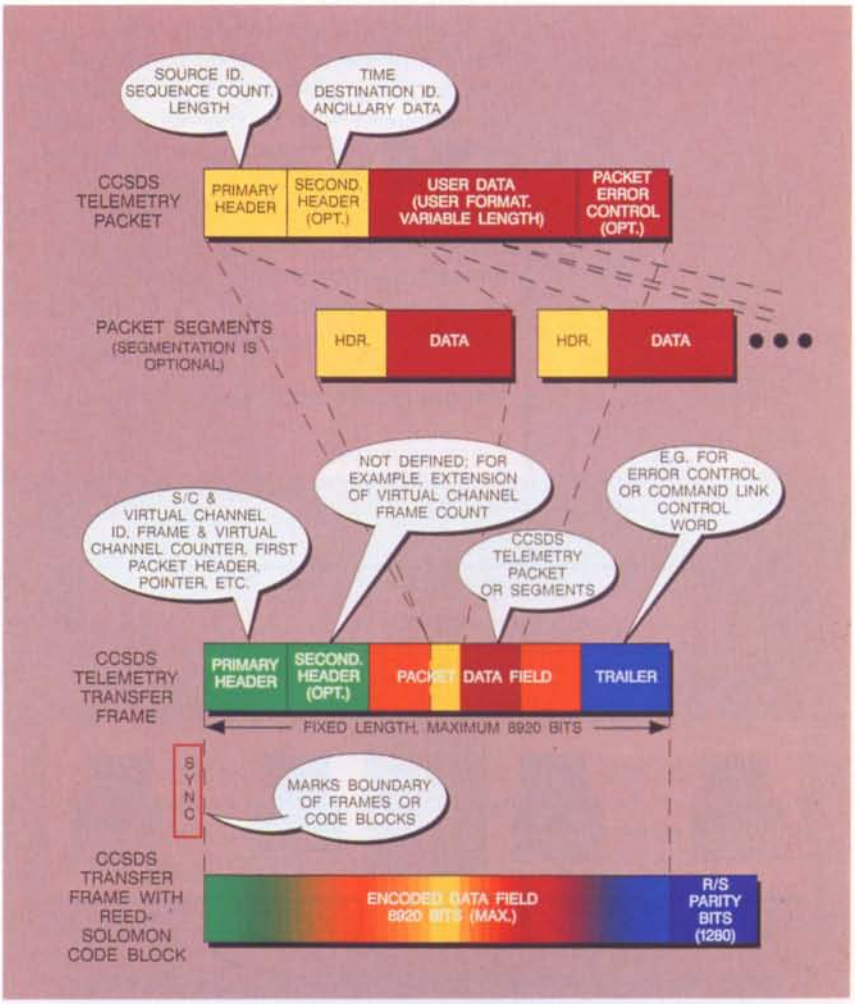


Figure 4. Characteristics of CCSDS space–ground link data structures, which follow the ISO principles for open systems interconnection as far as possible

The CCSDS validation programme for its 'AOS Recommendations', for example, one of the Committee's latest products, is based on use of the ISO Standard formal description language 'LOTOS' (Fig. 5). Four distinct phases are involved:

— *Phase 1. User requirements*
In this phase, the intent of the user is formulated in simple language.

— *Phase 2. Protocol specification*
Here a specification of the service and protocol is prepared, again in simple language, but using a more formal structure and methodology.

— *Phase 3. Formal description*
The formal-description phase provides an unambiguous specification in a form suitable for analysis by mathematical methods (e.g. using the LOTOS language supported by applicable LOTOS tools). Any obvious errors should be identified and rectified during this process.

— Phase 4. Implementation and test
The final phase of validation consists of providing an implementation and subjecting it to exhaustive testing. This not only allows further validation to be performed, but also provides an important means of checking that the original user requirements have been satisfied. As part of this phase, testing will be performed using communications links to remote implementations of the AOS protocols made by other space agencies.

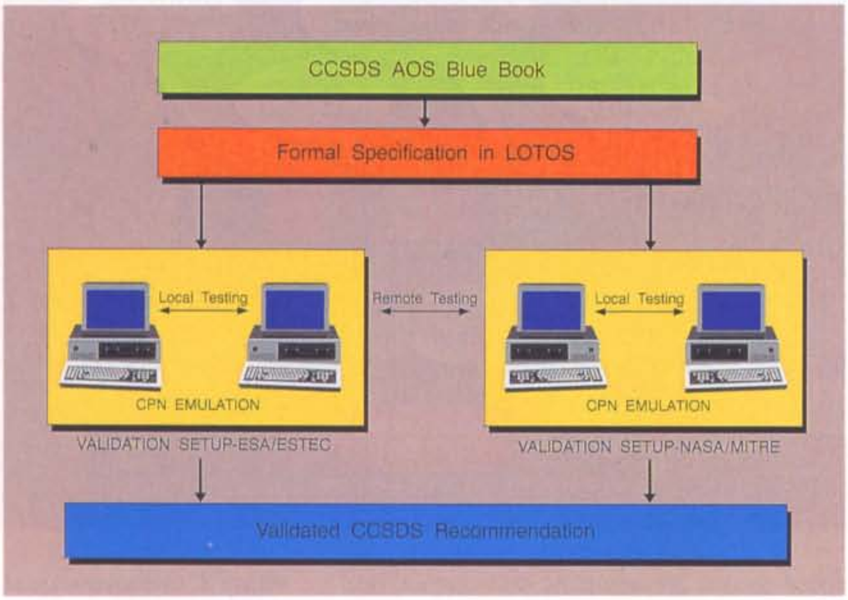


Figure 5. The CCSDS's validation programme for its AOS Recommendations

With the exception of Internet, all services and protocols defined in the AOS Blue Book will be covered by the validation programme (the Internet service is supported by an ISO protocol and is therefore accepted as already validated). Draft LOTOS specifications are already available for all AOS services and protocols. Suitable communication links are in place between ESTEC and NASA, and the testing of the Path protocol will begin in March, with the majority of remaining effort scheduled for completion before the end of 1990.

Technology support for CCSDS Recommendations

In addition to validating the Recommendations, ESA has supported the development of technology to enable the standards to be supported in flight-qualified technology. This development essentially involves devices to support the packet protocols and encoding standards.

CCSDS Recommendations related to Standard Formatted Data Units (SFDUs)

The Recommendations discussed in the previous paragraph relate principally to the movement of data from a source in space to a destination on the ground for telemetry, and in the reverse direction for commanding. The efforts devoted to the Standard Formatted Data Units (SFDUs) are related to locating and interpreting data in the context of interchanging information between data sources and data users, which may be separated both geographically and in time. It is therefore necessary to develop an Information Interchange System (IIS) based on standard methodologies that are known to and practiced by the participants.

The IIS (Fig. 6) must provide a series of services for the user who, regardless of his type of application, requires access to information that is not locally available. Some of these services are visible to the user, while others are internal to the system; for example, the IIS also interfaces in a layered sense with the underlying communications protocols and media, which can be electronic, tape, disk, etc.

The CCSDS Recommendation on 'Standard Formatted Data Units: Structure and Construction Rules' deals with the techniques for aggregating the several types of data that make up a typical scientific information interchange message. Not only the message itself has to be transferred, but also the associated data (so-called 'meta-data') that the user will require in order to understand and interpret the space-science data transmitted.

The SFDU concept therefore addresses a number of common problems of data exchange, including:
(i) the need to design new formats from scratch and to write specific software both to produce and read each new format; and
(ii) the lack of a guarantee on the availability of interpretation data throughout the useful life of the data.

The problems have been approached at two levels: namely the 'structure' level, giving the overall layout of exchange formats, and the 'data-description' level, which takes the format description down to the byte level.

At the structure level, the basic building block is Type Length Value Object (TLVO), in which the data is carried in the 'value field', its extent is specified in the 'length field', and the 'type field' gives, inter alia, a pointer to the description of the value field. A powerful set of Structure and Construction Rules is provided to allow TLVOs to be combined or aggregated into larger units or products, using techniques such as nesting. A validation programme for these Rules is currently under way.

At the data-description level, a number of approaches are possible.

In the simplest case the 'meta-data', or 'data descriptions', can be written in English and processed manually. As long as homogeneous computer environments are involved (same computer, operating system, etc.), automatic processing is also possible using a declarative programming language such as C, Pascal or Ada. The SFDU concept, however, aims to provide automatic handling of data formats even between different computer environments, and this is a very difficult problem for several reasons: machine dependency of data representation, of floating-point numbers, etc.

The CCSDS has made a careful study of the suitability of various languages for data transfer. The broad conclusion is that no existing programming language will fully satisfy the needs of heterogeneous intersystem transfer. The CCSDS has also examined the possibility of devising a purpose-built language, a so-called 'Data Description Language' (DDL), for this purpose. The Transfer Syntax Description Notation (TSDN) is one result of this effort. A promising approach currently under study is that of combining a programming language with certain elements of a data-description language like TSDN.

In the SFDU concept, each data description is registered with a 'Control Authority' (CA), which gives it a unique identifier. A CA registers, archives and distributes 'Data Description Packages' (DDPs) on request. A key aspect here is the discipline that the Control Authority imposes; raw data without descriptions are not permitted, and the Authority exercises a certain quality control over the data descriptions provided.

The Control Authority is formally headed by the CCSDS Secretariat, supported by a designated CA Agent, currently the World Data Center A for Rockets and Satellites.

CCSDS services and products

Soon after the publication of the first CCSDS Recommendations, the technical and practical aspects of inter-agency cross-support came under discussion. The term 'CCSDS Services' was introduced as an element of the space data system via which cross-support can be provided to those users whose systems are designed according to CCSDS Recommendations.

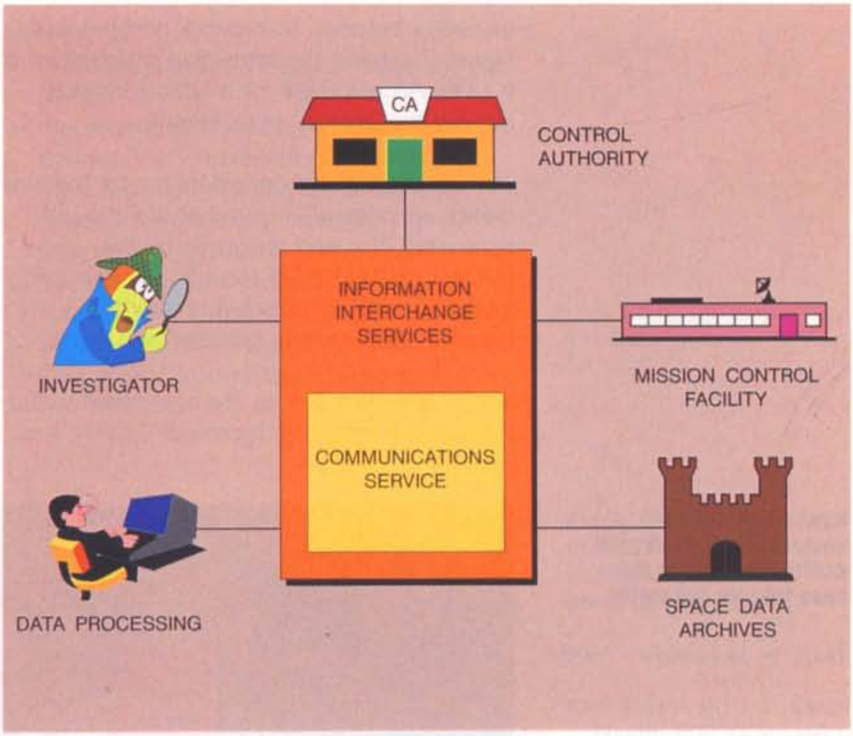


Figure 6. The Information Interchange System (IIS) ground environment

CCSDS Panel 3 was thus created in March 1987 to develop technical Recommendations for standardised cross-support services, their associated access points, access mechanisms, and their technical management. In the near-term, Panel 3 will deal mainly with the ground-related classical services of telemetry, telecommand, navigation, etc., and especially with the sustaining ground communication services. This should cover the needs for conventional missions, space-bound access points falling in the domain of Advanced Orbiting Systems (AOS), which will be addressed by the Panel as a follow-on task.

A 'service' is defined by the relationship between a 'service user' and a 'service provider', which in the CCSDS context are usually both agencies. The service itself usually involves exchanging application data (e.g. telemetry, telecommands) with the support of a pre-determined communications standard including application protocol and the specification of exchanged data units. The management of this service is quite different from that of the underlying communications, and these two aspects may fall under different responsibilities, with one Agency responsible for the service management and another for the communications management. Each Agency provides one or more CCSDS Ground Network (CGN) Access Points (CAP), which form the gateways between its network and the CGN. Figure 7 depicts the functional architecture of a CGN Access Point for a typical service, namely the delivery of telemetry.

The services under consideration for the time being are primarily those that are ground-accessed. The end result will be the publication of CCSDS Blue Books specifying precisely and completely the interface between the service's provider and user.

All CCSDS Blue Books are committed to the principle of long-term technical stability, and are published only after a thorough process of technical discussion and review in the CCSDS Panels and by CCSDS Member and Observer Agencies (Fig. 8). More than 20 Green and Blue Books have already been published, and a number of others are currently under review. Endorsement of the CCSDS's Recommendations is entirely voluntary, but it indicates the understanding that, whenever an Agency establishes a CCSDS-related 'Standard' it will be in accord with the relevant Recommendation.

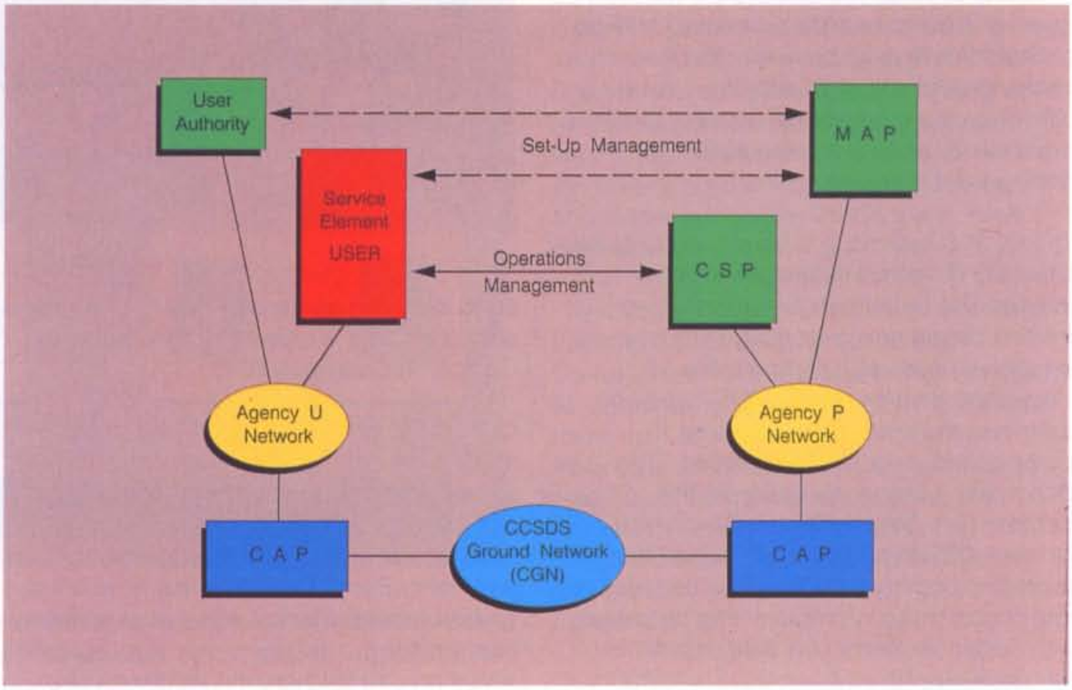


Figure 7. Functional architecture for a typical CCSDS Service, in this case that for telemetry

MAP = Management Access Point
CAP = CGN Access Point
CGN = CCSDS Ground Network
CSP = Cross-Support Point
U = User
P = Provider

The CCSDS Member and Observer Agencies are all in the process of adjusting their Standards to the CCSDS Recommendations. ESA and NASA have prepared or are currently preparing several CCSDS-related standards.

The following ESA Standard has already been issued:
- Packet Telemetry Standard, January 1988 (PSS-04-106);

and five more are in preparation:
- Radio Frequency (RF) and Modulation Standard, December 1989 (PSS-04-105);
- Packet Telecommand Standard, 1990 (PSS-04-107);
- Telemetry Channel Coding Standard, 1990 (PSS-04-103);
- Time Code Formats and Procedures Standard (PSS-04-202), expected 1990/91;
- In-Orbit Infrastructure: Network and Data-Link Protocols (PSS-04-108), expected 1990/91.

The following NASA Standards for deep-space missions have already been issued:
- Standard for Telemetry Channel Coding, July 1985 (TLM-1);
- Standard for Time Code Formats, July 1986 (TIM-1);
- Standard for Radiometric & Orbit Data, July 1986 (ROD-1);
- Standard for Command Channel Service, August 1989 (CMD-1).

The following NASA Standards for deep-space missions are currently in preparation:
- Standard for Packet Telemetry (TLM-2);
- Standard for SFDU Structures (SFD-2).

Other CCSDS Member and Observer Agencies are expected to adopt these Standards in due course.

The NASA Office of Space Operations has baselined the CCSDS Advanced Orbiting Systems Recommendations for future Earth-orbiting satellites requiring its support, while the NASA Office for Space Station is currently baselining the same document for the International Space Station 'Freedom'.

Application of CCSDS Recommendations in ESA projects

The prime purpose of the CCSDS activities is to provide for harmonisation of space data systems for projects involving hardware from several different agencies. These agencies will find it advantageous to take the CCSDS Recommendations into account for such large projects because of the cost, schedule and risk reductions inherent in using existing capabilities and designs.

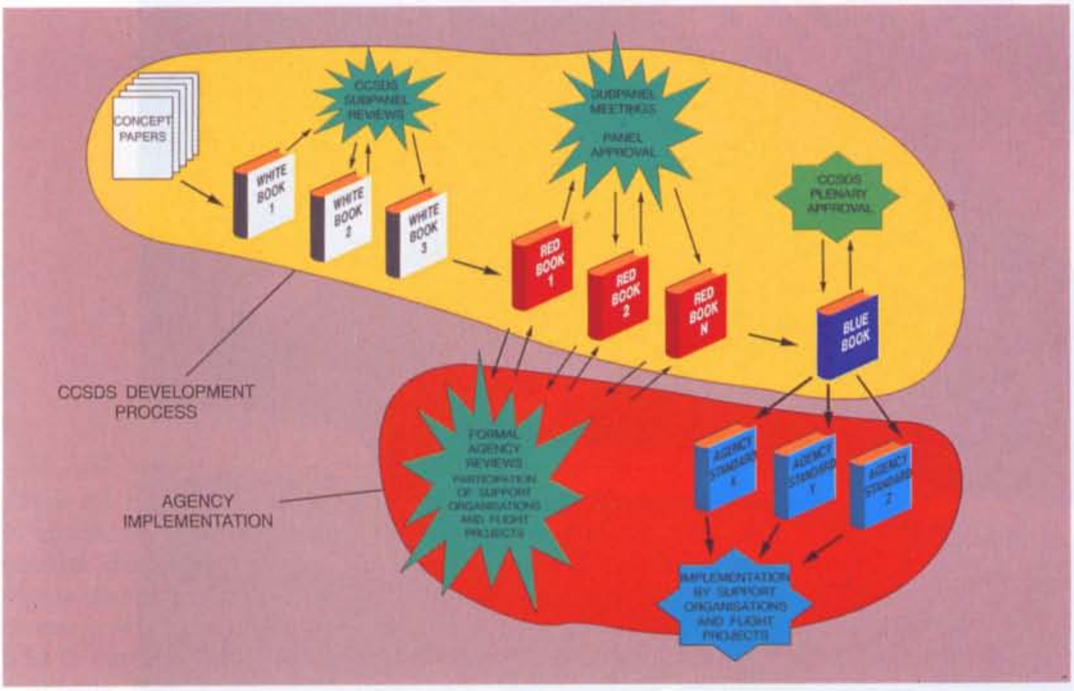


Figure 8. Schematic of the CCSDS Recommendation and Agency Standard production process

The following ESA/cooperative projects have already adopted (fully or partially) CCSDS Recommendations:

- Eureca, the European Retrievable Carrier, which will be deployed and retrieved by the Space Shuttle;
- the Soho (Solar and Heliospheric Observatory) and Cluster (four spacecraft in non-coplanar, highly eccentric orbits with adjustable separation distances) missions, belonging to the International Solar-Terrestrial Science Programme (STSP).

Furthermore, ESA's new CCSDS-compatible Packet Telemetry and Telecommand Standards and, where applicable, the CCSDS AOS Recommendation, will be the baseline for:

- the European Data-Relay Satellite System (DRS);
- the second generation of European geostationary meteorological satellites;
- the Columbus Programme (manned space laboratories, permanently or temporarily docked to Space Station 'Freedom', plus a Polar Platform);
- Hermes, the European manned transport vehicle, planned to be used with Columbus, Space Station 'Freedom' and also MIR.

ESA's Director General has recently decided that for all future ESA projects, CCSDS-derived standards will be mandatory and all ESA Standards will be supplemented accordingly. The other European space agencies that are members of the CCSDS, i.e. BNSC (UK), CNES (F) and DLR (D), have adopted most ESA Standards in the past and the projects of these agencies will therefore probably also follow most CCSDS Recommendations in the future. ESA is committed to the CCSDS philosophy, and all relevant Recommendations are being used to derive the corresponding ESA Standards.

Mechanical Coolers: An Option for Space Cryogenic Cooling Applications

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There are three basic options for achieving cryogenic temperatures in space: radiative cooling, cryogen cooling, and mechanical coolers. Both the radiative and cryogen options can fail to meet the highly-demanding requirements for future space missions in terms of temperature, long life and low mass. The mechanical coolers that ESA is currently developing can overcome several of these major problems, thereby providing much greater flexibility in overall spacecraft configuration compared with current cryogenic cooling designs.

Introduction

Why cool anything in space to cryogenic temperatures — which can be loosely defined as temperatures below 120 K or −153°C?

Although communications, life-support and life-sciences applications could also benefit from any advances made in space cryogenic cooling technology, it is the scientific disciplines (astronomy, Earth observation, astrophysics, etc.) that will undoubtedly benefit most in the short term. Here the majority of the cooling options are associated with the requirements of detectors that use their unique position in space to benefit from either the Earth-viewing possibilities, the elimination of the perturbing effect of the Earth's atmosphere, or to a lesser extent the microgravity environment.

Many people are already benefiting daily from space cryogenics when they look at their television weather forecast, since the infrared detectors on board the European Meteosat spacecraft are cooled to approximately 100 K. However, further significant improvements in the scientific data available from such an instrument can be limited, even at 100 K, by the inherent thermal noise of the detectors, highlighting the strong correlation between sensitive measurements and cryogenic cooling.

Although the present problem is often one of reducing detector thermal noise, some sophisticated detectors, such as those using superconductors, need cryogenic temperatures in order to work at all. This makes the availability of sensible cryogenic cooling options a must for future scientific satellites.

The cryogenic cooling options in space

With the background temperature of deep space known to be in the neighbourhood of 3 K (−270°C, or 3 deg above absolute zero), it is ironic that cryogenic cooling in space should pose any problem at all. What one must remember is that in a hard vacuum (less than 10^{-7} mbar) such as exists in space, the heat exchange between a spacecraft and its surroundings is purely radiative. Heat inputs for an Earth-orbiting satellite come from: a direct solar flux (approx. 1400 W/m^2), a reflected solar flux from the Earth (approx. 350 W/m^2), and the infrared flux from the Earth itself at a temperature of approximately 250 K. The temperature of a spacecraft can hence be controlled (rather fortunately for manned missions) by the appropriate choice of its surface's thermo-optical properties, whereby a cold surface, such as white paint, would be expected to have a low absorptivity in the solar part of the electromagnetic spectrum, and a high emissivity in the infrared.

For cryogenic-cooling purposes, it would be better to coat the whole of the spacecraft's external surface with white paint, resulting in typical external temperatures of 100 K for a 24 h, high Earth orbit. In reality this is not possible, due to the need to keep certain units and components (e.g. in the attitude and orbit control, power, and telemetry subsystems) at or close to room temperature (290 K). Hence the cryogenic part of any satellite is subject to similar constraints to those here on Earth, and must be designed to be thermally decoupled from the necessarily room-temperature parts of the satellite.

There are basically three cryogenic cooling options in space: passive (radiative), cryogen, and mechanical coolers (cryocooler). Passive cooling is understood to mean radiative cooling via coupling to deep space. The main advantages of passive cryogenic radiators are their high reliability over extended periods, and (normally) zero power consumption. Unfortunately, the cooling power of a radiator of fixed area diminishes with the fourth power of the temperature (Stefan Boltzmann's law), essentially limiting the base temperature for small heat-lift requirements (about 1 W) to 80 K when permanently deep-space pointing, and to 100 K for practical applications such as Meteosat. Problems can arise from the need to maintain the thermo-optical properties both during pre-launch activities and in-orbit, while on-ground verification and in-orbit pointing constraints are likewise subjects of concern.

Cryogen cooling in space can be likened, somewhat crudely speaking, to the launching of a thermos flask (or cryostat) full of liquid cryogen (sometimes solid) boiling at a very low temperature (Table 1). The problem of fluid retention in zero gravity originally led to a preference for flying solid cryogens, with its associated problems of complicated pre-launch activities, and the low thermal conductivity of the cryogen in the solid phase. However, due to the practical impossibility of solidifying helium, and also the safety aspects of solidifying hydrogen, the temperature limit for a solid cryogen is essentially that given by the use of neon. For missions such as IRAS, and now ISO, where even lower temperatures are required for infrared-detector applications, superfluid liquid helium is used.

Table 1. Boiling points (deg K) of some of the more common cryogens (at 1 atm)

Helium 3	3.2
Helium 4	4.2
Hydrogen	20.4
Neon	27.2
Nitrogen	77.3
Argon	87.4
Oxygen	90.1
Methane	111.7

Problems associated with the use of any cryogen (solid or liquid) are the very high mass-to-lifetime ratio (with ISO requiring a 1.3 ton cryostat for a lifetime of 18 months), the complicated pre-launch activities, and the difficult on-ground verification procedure. Nevertheless, the use of cryogen cooling is highly reliable, being a totally passive device, well adapted to large-surface-area cooling via the boil-off of gas, and is unlikely to suffer from any problems due to inherent vibration or temperature instability.

Cryocooler cooling is achieved by means of a device in which work is done in a closed thermodynamic cycle in order to pump heat from a cold environment to a hot environment. Such 'refrigerators' are comparatively common in many ground-based laboratories and industrial plants. However, all practical present-day machines of this type contain rubbing surfaces, which eventually wear away. Unless such technologies as magnetic suspension or clearance seals are used, this will normally lead to mean times to failure of approximately 5000 h. For space applications, such a limited operating lifetime is unacceptable and probably not competitive in relation to a small cryostat. Hence, although it was expected even in the 1970s that the only viable long-life (greater than three years), high-heat-lift, cryogenic cooling option was a cryocooler, several technical problems needed to be overcome, including:
- an increase in reliability
- a reduction in power consumption
- minimisation of mass and size
- minimisation of any inherent vibration.

The degree to which these problems have now been solved forms a major theme of this article.

Future trends

Future requirements foresee the general temperature-demand trend continuing downwards, but more importantly there are strong requirements for longer lifetimes and higher cryogenic heat lifts. The greater heat-lift demands usually stem from the fact that single detector chips are being replaced by arrays of such chips, with increased support-structure and wire-related heat loads. The longer-lifetime requirement comes not only from a cost versus scientific-return argument, but also one of in-flight experience. This indicates that a certain minimum period is required to learn how to operate a complex instrument optimally. Moreover, it can sometimes take as much as a year for an observatory satellite to be back in a position where it can repeat an earlier, particularly interesting observation. These trends can be demonstrated by looking briefly at just four possible future European missions.

Meteosat Second Generation

The Agency's Second-Generation Meteosat spacecraft programme is intended to provide 10 to 15 years of continuous meteorological data, commencing in approximately 1998, as a replacement for the current Meteosat Operational Programme (MOP) satellites. The highest-priority instrument on board operates in the visible and infrared, where the detectors benefit from cryogenic cooling to at least 100 K, and preferably 80 K. A total of three or four satellites with a minimum operational lifetime of 5 to 7 years (per satellite) is required. This essentially precludes any form of cryogen cooling, due to lifetime and mass constraints. The three-axis-stabilised satellite option that is passively cooled to 100 K would require an unusual spacecraft configuration incorporating a solar sail to balance the solar-radiation torque with negligible heat input into the radiator; on the other hand, 80 K cooling with mechanical coolers would allow a classical spacecraft configuration.

Polar Platform

The Polar Platform forms a major part of the European Earth-Observation Programme, and most Earth-pointing instruments detecting in the infrared (such as those using Hg/Cd/Te detectors) will require cooling to 80 K, with some instruments using SiGe detectors (e.g. limb sounders) calling for cooling to 40 K.

The number of such instruments requiring cryogenic cooling on the first European platform, due for launch before the year 2000, is not presently known but, owing to the nature of the observations to be made, is expected to be significant. Relatively long lifetimes (greater than four years), and the unfavourable thermal environment in a low Earth orbit, make the use of passive or cryogen cooling extremely unlikely.

FIRST

The Far-Infrared Submillimetre Space Telescope (FIRST), one of the Agency's scientific Cornerstone missions due for launch after the year 2000, will operate at wavelengths between 0.1 and 1.0 mm. FIRST has recently become the subject of a systems-definition study that will investigate the project's technical feasibility based on strict cost, scientific and mission requirements.

The superconducting mixers of the heterodyne instruments require cooling down to 4 K, while the photometry and spectrometry detectors require 2.5 K cooling. Unlike the ISO project, the optics do not require cryogenic cooling and the minimum lifetime is 3 years, with a goal of 6 years for the heterodyne instruments.

Future scientific missions

In 1988, after several parallel feasibility studies, the Agency selected Huygens as its next medium-sized scientific mission. Some of the competing projects included the Gamma Ray with Spectroscopy and Pointing (Grasp), and Quasar Satellite (Quasat) missions. Grasp was designed to operate as a high-sensitivity spectral imager in the gamma-ray region of the electromagnetic spectrum, while Quasat was a free-flying, very-long-baseline interferometry antenna operating at between 1 and 22 GHz. Both required cryogenic cooling down to 80 K, with heat lifts of a few watts and operational lifetimes of a couple of years.

As the scientific interest in Grasp- and Quasat-type missions has not diminished, it is to be expected that future medium-sized scientific missions will require some form of cryogenic cooling, which is unlikely to be fulfilled by passive or cryogen cooling.

Figure 1. The BAe 80 K cooler

ESA's cryocooler development effort

Based on the trends highlighted above, the Agency has been interested in cryocooler development since 1982, actively supporting a promising development effort taking place in the United Kingdom. This Oxford University/Rutherford Appleton Laboratory/ British Aerospace development programme was initially funded mainly by the UK Science and Engineering Research Council (SERC), with substantial funding subsequently being furnished by ESA and BAe.

This cooperative endeavour has its origins in the late 1970s, when pressure modulators were flown for atmospheric-research purposes on three Nimbus satellites (-6, -7 and -F). Because of the failure of the radiative coolers to cool the detectors to cryogenic temperatures on at least one of these satellites, Oxford University began to investigate the possibilities of active cooling. They realised that the mechanism used for the successful pressure modulators (five years of unattended operation) could be applied to a split-single-stage Stirling-cycle cooler. Further work culminated in the development of an 80 K Stirling-cycle cooler for a Space-Shuttle-launched atmospheric research instrument called 'ISAMS', (Fig. 6) which was the forerunner of the present BAe/ESA-funded cooler. These ISAMS coolers have already successfully undergone flight-model testing at Oxford, and the instrument is due for launch in 1991.

The 80 K cooler

The 80K cooler design is based on a thermodynamic split Stirling cycle, in which work is done in compressing gas inside a compressor. The heat generated is dissipated at approximately room temperature, and the same gas is allowed to expand inside the cold tip of the displacer, thereby producing a cooling effect (Fig. 2).

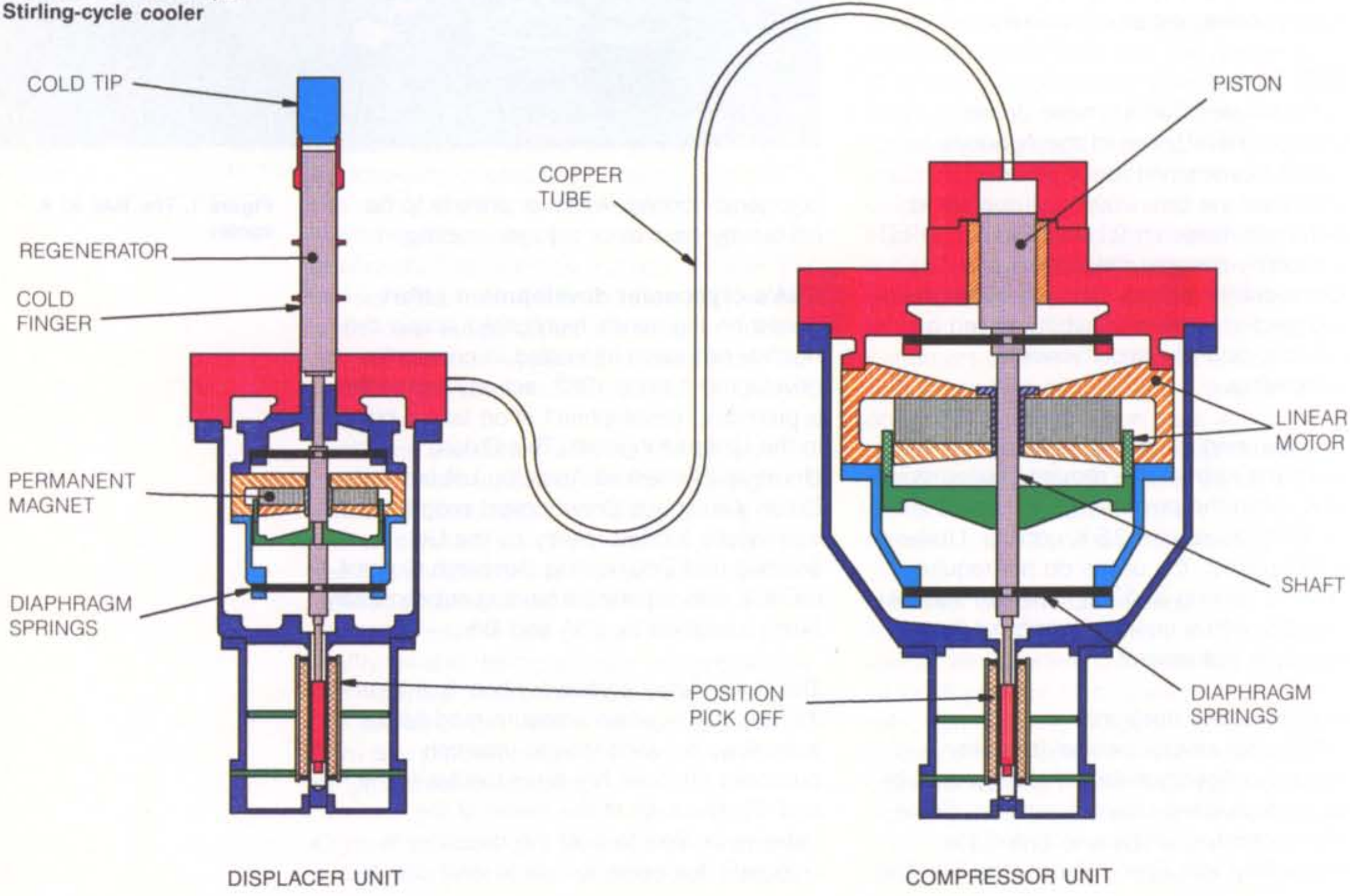
The compressor consists of a piston mounted on a shaft, which in turn is mounted on diaphragm springs that give axial freedom but are radially rigid. The linear motor causes the shaft, and hence the piston, to oscillate at a frequency of 40 Hz. This superimposes an oscillating pressure cycle of nominally 1.5 bar on the mean vessel pressure of 14 bar, with helium as the working fluid. This pressure cycle is transmitted to the displacer via a copper tube, which allows flexible independent mounting of these two mechanical units. The displacer contains a reciprocating regenerator stack (basically a heat exchanger) mounted on a similar shaft system to that in the compressor. When the motions of these two mechanisms are correctly phased, heat is progressively removed from the cold tip until the operating temperature is reached and maintained. The two mechanisms operating at 40 Hz are maintained in a precise phase relationship by closed-loop drive electronics.

This cooler design achieves long life and high reliability through the following features:

(i) gas clearance seals eliminate all rubbing parts;

(ii) the gas clearance seals are maintained by diaphragm support springs, which operate at dynamic stresses well below the material fatigue threshold. Such dynamic stresses are consistent with infinite fatigue life, proven by six years of operation in the pressure modulators on the Nimbus spacecraft;

Figure 2. The 80 K split-Stirling-cycle cooler



(iii) the cooler has a conservative thermal design and the compressor operates at close to its resonant frequency;

(iv) cooler acceptance leak-test levels of 1 x 10^{-7} m bar l/s ensure end-of-mission performance consistent with no apparent deterioration in less than 100 years!

The 80 K cooler is currently available as an industrial 'off-the-shelf' production item. It can already be considered 'space-qualified' (Table 2), and prototype life tests have presently (February 1990) achieved 26 000 and 19 000 h of operation (Table 3).

Several of the cooler's operating parameters are variable, and higher or lower heat lifts, for example, can be obtained by varying the power input, the interconnecting pipe length, and the cooler's external shell temperature. The cooler can be also be tuned to operate over a given temperature range, and is therefore not simply a cooler for use at 80 K (see Fig. 3, which can be extended to higher temperatures).

Table 2

Parameter	Nominal Value
Heat Lift at 80 K	800 mW
Lifetime	10 years (goal)
Temperature	
Storage	−45°C to +85°C
Operational	−20°C to +40°C
Launch Vibration Survival	
Random	80—350 Hz at 0.24 g^2/Hz or 100—1200 Hz at 0.25 g^2/Hz
Sinusoidal	5—80 Hz at 2 oct/min. constant amplitude or 8 g peak
Self-Induced Vibration	
Compressor	0.1 N.sec peak (uncompensated) 0.001 N.sec rms (compensated) (Based on ISAMS Test Data)
Mass	
Compressor	3.0 kg
Displacer	0.9 kg
Electronics	3.5 kg
Power Consumption	
Compressor	30 W
Displacer	1 W
Electronics	9 W
Size Envelope	
Compressor	200 mm long × 120 mm dia.
Displacer	212 mm long × 75 mm dia.
Electronics	251 × 254 × 124 mm^3
Power-Supply Requirements	+28 V, ±15 V and + 7 V
Operating Frequency	40 Hz

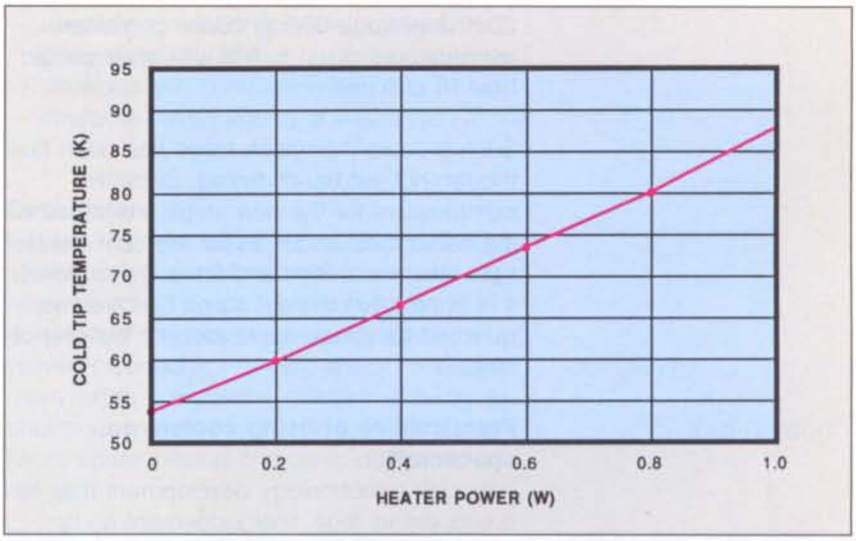


Figure 3. Performance curve for the 80 K cooler

Other cooler developments

Although the 80 K cooler can be used over a range of temperatures, temperature-gradient limitations in the displacer cold finger mean that there is little or no cooling below 55 K, and further reductions in temperature require two stages of cooling within the finger. The decrease in cold-finger temperature also calls for an increase in compressor swept volume, and hence in the number or size of the compressors. Such a dual-stage Stirling-cycle cooler is currently being developed at RAL using the proven long-life mechanisms of the 80 K cooler as extensively as possible (Fig. 4).

The nominal operating point for this cooler is expected to be around 20 K to 30 K. So far, it has only been bench-tested (Fig. 5), but its similarity to the 80 K cooler should allow it to be space-qualified by the end of 1992 (Table 4).

To descend further in temperature, it is possible to add another stage to the displacer cold finger. However, the heat capacity of the helium gas at temperatures lower than 20 K becomes comparable with that of any heat exchanger (regenerator) material used, and so a cooler working at 30 Hz becomes very inefficient. RAL and ESA have therefore chosen to explore another thermodynamic cycle, namely the Joule-Thompson cycle, in which the free expansion of helium gas pre-cooled with the

Table 3

Lifetime (years)	3	5	7	10
Mechanical Reliability	0.985	0.976	0.966	0.952
Electronic Reliability	0.995	0.992	0.989	0.984
Overall System Reliability	0.980	0.968	0.955	0.937

20 K dual-stage Stirling cooler produces temperatures down to 4 K with an expected heat lift of 5 mW.

Such a Joule-Thompson stage has been built though not yet bench-tested. Since the compressors for the new stage are based on the same mechanism as for the 80 K cooler (gas clearance seals and linear-motor drive), it is hoped that the 4 K stage can also be qualified for space application by the end of 1992.

Practicalities of using coolers on spacecraft

Although a technology development may be a success in itself, final judgement on its practicality must await its baselining for flight on board a spacecraft and its ultimate operation in space. Many practical constraints can come into play at this stage in addition to the more fundamental problems of mass, cost, etc.

Table 4

Parameter	Nominal Value
Heat Lift	
at 30 K	300 mW
at 20 K	60 mW
Total Power Consumption	115 W
Mass	
Compressors (×2)	7.0 kg
Displacer	1.3 kg
Electronics	7.0 kg
Size Envelope	
Compressors	130 × 140 × 161 mm^3 each
Displacer	75 × 75 × 209 mm^3
Electronics	Not yet formulated

Ground testing

Cryostats designed for long lifetimes or high-heat-lift applications need a significant volume of cryogen (the Agency's ISO spacecraft will contain 2200 l of superfluid helium) for relatively small payloads, leading to time-consuming ground operations and expensive testing. On the other hand, cryocoolers only cool what needs to be cooled, namely the detectors. The risk of leaks into the instrument vacuum should also be reduced and the demountability of the instrument should be vastly improved. The coolers will, however, need to be shown to be capable of operation in any orientation, as ground tests often involve the satellite being tested in many different positions.

Pre-launch activities

Normal Ariane pre-launch activities involve a 72 h period prior to lift-off during which only electrical access to the payload is available. For a satellite carrying cryogen under vacuum, this creates a problem due to unacceptable heat leaks into the cryostat during such a period. The solution retained for ISO is to incorporate an auxiliary tank of helium at 4.2 K (1 atm) and drive off the helium gas at the requisite rate for cooling by controlled electrical heating (see ESA Bulletin No. 57, pp. 53–58).

The pre-launch activities for a cryocooler-cooled instrument should be relatively simple. If the instrument is to be launched cold, the level of power required will have to be closely investigated and the ability to dissipate the heat produced inside the fairing checked. However, with a cryocooler it is also possible to launch the instrument at room temperature and cool it down in orbit. This option imposes no constraints on the launch campaign, but such problems as possible loss of instrument alignment during the in-orbit cool-down will have to be verified.

Mass

The mass of a cryocooler system involves not only that of the coolers themselves, but also

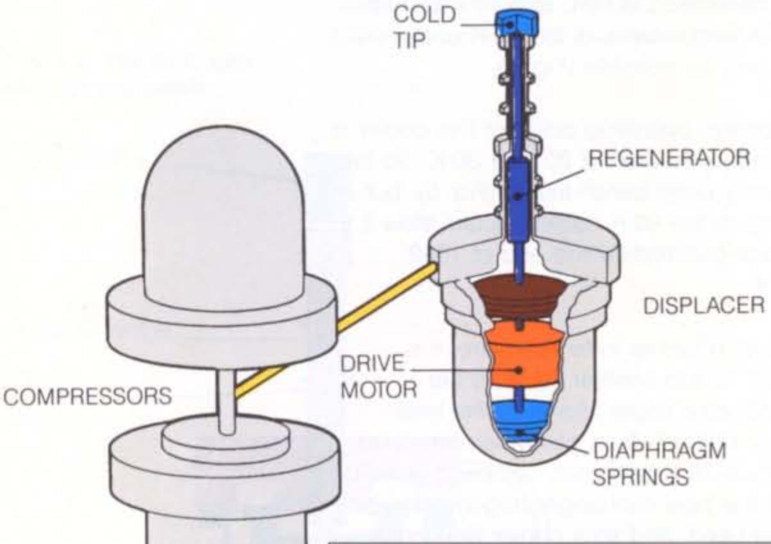


Figure 4. The 20 K dual-stage Stirling-cycle cooler

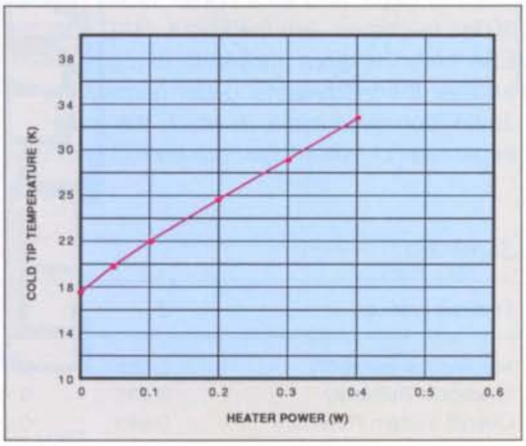


Figure 5. Performance curve for the 20 K cooler

that of the radiators needed to dissipate the heat that they produce, the extra solar panels, and the increased battery capacity necessary for operation during eclipses. Hence, although there will be a significant mass advantage in using cryocoolers instead of a cryostat (especially if the outer vacuum jacket can be dispensed with), it may not be so substantial as it appears at first glance.

Self-induced vibration

The present cryocoolers have compressors with a moving mass of approximately 150 g. Although extremely small in relation to the total mass of a satellite, for spacecraft making sensitive measurements thought must still be given to their possible consequences in terms of detector 'wobble' and the overall error on any spacecraft pointing budget. No such problems exist for a cryostat.

Reliability

Despite the impressive reliability figures shown in Table 3, the spectre of a single-point failure for cryocoolers will probably entail the baselining of a redundancy philosophy. This must either envisage all the coolers running continuously, or a design that can compensate for the extra heat leak coming from a non-operating cooler, with or without the use of a thermal switch to decouple it.

Further development

Further development effort is still needed to finalise the present 80 K cooler and to continue cooler developments to still lower temperatures, with a 2.5 K cooler as the next goal. Future work foreseen includes:

For the 80 K cooler:

- continuation of lifetime testing, up to ten years
- further characterisation of self-induced vibration, and alignments necessary to comply with the most sensitive detectors
- further spacecraft launch vibrational testing
- additional thermal characterisation, such as operation at lower external shell temperatures, and
- improvement of drive electronics in terms of mass, power, reliability, and modular construction.

For the 20 K/4 K cooler:

- transfer of technology to industry
- lifetime testing (present units have run for more than 2000 h)
- self-induced-vibration characterisation
- proof of launch-vibration survivability
- general performance characterisation of 20 K cooler
- upgrading of laboratory electronics to flight standard, and
- development, completion and characterisation testing of 4 K stage.

Conclusion

It is unlikely that radiative or cryogen cooling alone can efficiently cover all future user requirements. The introduction into the equation of the use of a reliable space-proven cryocooler, however, should overcome many existing problems, thereby allowing an enormous increase in the flexibility of any future space-related cryogenic design.

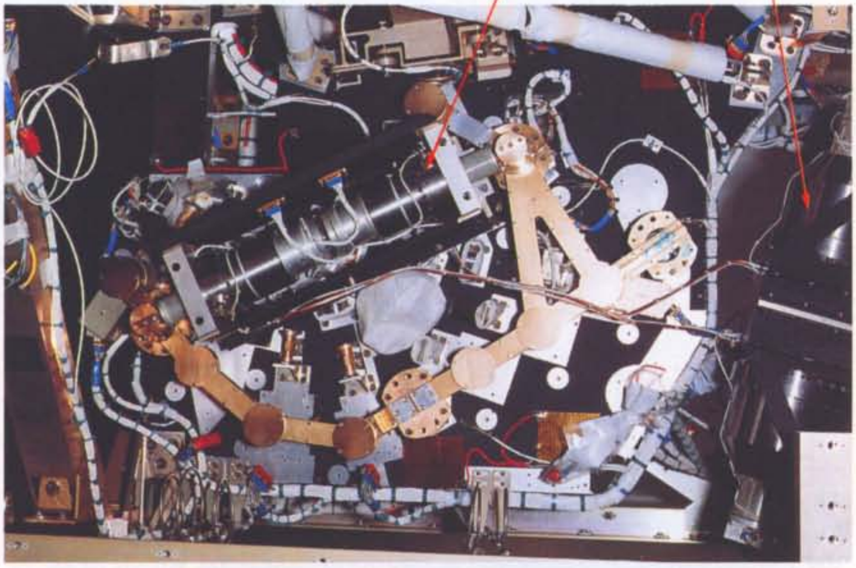


Figure 6. View of the 'ISAMS' instrument

The development of space cryocoolers has long been recognised as necessary (especially by the USA), and it is a European development that is showing the first indications of fulfilling the strict requirements involved. Successful completion of this work is expected to lead to the acceptance of cryocoolers as a serious cryogenic cooling option for space applications, capable of delivering performances that have previously been considered unachievable.

Acknowledgements

The development of the coolers described in this article has benefited and continues to benefit from work performed at Oxford University and the Rutherford Appleton Laboratory (RAL) in the United Kingdom.

EFSY — The Backbone of ESA's Financial-Control System

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As ESA has grown and expanded over the years, the requirements for managing its finances have grown and expanded with it. Today the management of traditional accounting functions which need to be provided at all times, such as visibility of expenditure, revenues, assets and liabilities, has been coupled with providing a variety of statistical and associated data for effective management procedures and sound decision making.

In addition, due to its unique inter-governmental composition, with its thirteen Member States, the Agency is obliged to provide specialised information and data not normally required in other industrial or research organisations, including, for example, the retroactive adjustment of each Member State's financial contribution at the end of a given financial year. The managing of ESA's finances has, therefore, over the years, become a highly intricate and demanding task.

Background

In the early years, when the Agency was involved in only a few projects, financial data-processing needs could be amply satisfied with punched cards running in so-called 'batch mode', a processing method whereby financial-transaction data were accumulated over a certain period and then electronically processed in a single batch. In today's world, with ever-increasing pressure for well-timed decision-making and reliable planning, the Agency could not possibly keep pace if it had not substantially upgraded its financial data-processing methods.

In 1982, the ESA Executive entered into a contractual agreement with IBM for the development of an appropriate financial-management software package for the Agency. This software was first implemented in 1984 under the acronym 'EFSY' (ESA Financial System), a name that has been retained ever since. As new financial-management and data requirements have emerged, the EFSY software package has been systematically upgraded. Today, the package contains more than 1400 individual programs, each of which performs a unique set of machine instructions.

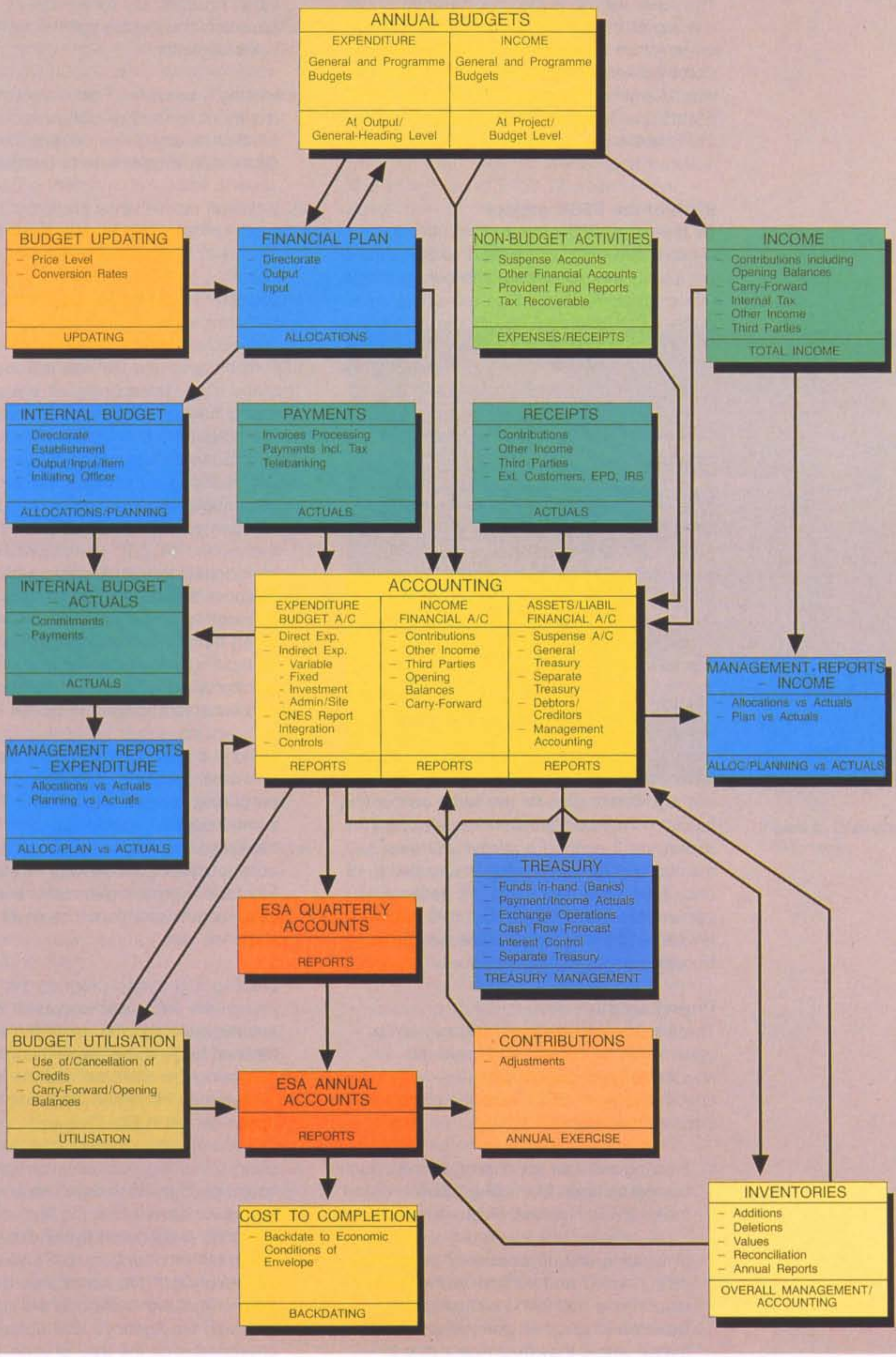
EFSY is based on an advanced programming language (AS) which, besides providing great potential for further expansion, makes maintenance and operations much easier. The principal functions of the EFSY package are highlighted in Figure 1.

In designing the EFSY software package, its architects were looking to the long term: the software was to be based on proven technology and on a range of the envisaged manufacturer's (IBM) strategic products. This is an essential precaution when one appreciates that the working life and reliability of software depends to a great extent on a guarantee of maintenance and on the quality of the basic tools used to create it. EFSY is thus the outcome of taking a calculated risk back in 1982/83 - wagering that the IBM environment would predominate; that the electronic data-processing (EDP) tools used would remain available for a long time to come; that development of personal computers connected to a mainframe would flourish; and that the telecommunications networks, without which EFSY in its present form could not exist, would expand.

At the same time that the software was being developed, the ESA Computer Department undertook a hardware upgrading and harmonisation exercise, which included the ESANET network. Today, therefore, a user can have financial data 'moved around' from one point in the Agency to another, simply and surely, via a multiplicity of machines and software products.

Over the years, there have been many additions and improvements to EFSY. The first version was written in 1982/83 to work in IBM's 'International Service Bureau' environment, but during 1986 the software

Figure 1. Functions of the EFSY software package



was fundamentally changed so that it could be moved onto the Agency's own computers. This latter version is the one currently running at ESOC, in Darmstadt. EFSY can currently be accessed by more than 100 users located in the Agency's five main establishments (Headquarters, ESTEC, ESOC, ESRIN and Toulouse), most of whom are in the Finance Department.

Birth of the EFSY project

By the early 1980s, the existing administrative software had reached such a state of complexity that modifying it further no longer made sense. A situation existed where each Agency Establishment had its own programs, running on a variety of hardware platforms. Also, the outdated system was ill-suited to the reform of ESA's structure undertaken in the mid-1970s, which set up Programme Directorates with staff and activities located in several different Establishments.

The time required to generate the monthly consolidated financial figures grew longer and longer, and by 1982 was at least a week. At that time, the concept of computer networking was very new and most of the machines in use were unable to work in other than local mode. Data was moved from place to place on magnetic tape.

It is not surprising, therefore, that those programs tended to develop along individualistic lines and there could, for instance, be up to four separate programs in use at different sites for the same accounting function. That configuration was also very expensive; it needed a relatively large maintenance team with expert knowledge of each type of hardware used. It became apparent to the Administration that a total rewrite of the financial software system had become inescapable.

Project aims

The first consideration in designing a new system was, of course, to remove the shortcomings of the old one. The specifications for EFSY were therefore directed towards:

- creating a single set of programs for each budgetary and accounting function called for by ESA's Financial Regulations;
- eliminating any duplication of data; every item inputted and verified by the person responsible had to be immediately available to all other users affected, no matter where they might be located;
- unifying the procedures for accessing and processing financial data, thus limiting as far as possible any differences of approach that there might be between Establishments;
- making it possible to get a consolidated picture of the budget and accounting situation at any given moment, by either Directorate, Programme or budget output;
- reducing maintenance costs, by using a modular design that made it simple to alter or to add applications.

In addition to these basic requirements, there were technical options to investigate which could accommodate foreseeable changes in EDP techniques and the Agency's needs. This was difficult to accomplish in a very fast-changing environment, but now, six years later, the flexibility and high overall performance of ESA's current system is due very largely to the sound choices that were made at that time. The most critical areas included:

- abandoning the batch capture of data in favour of a real-time method which, although technically more complex, is much more user-friendly (with the new method, individual transactions entered on a terminal or PC are immediately verified and accepted or rejected by the system);
- setting up a single and unique financial database, made up of independent files containing specific kinds of data (budgets, commitments, invoices, etc.) and centralised on the same site; with this configuration, it is very easy to add new functions by creating new files without disturbing existing functions or increasing response time;
- creating a checking program that recognises each user logged-on and automatically supplies the authority (defined by Finance Department) for accessing the database and the functions available on EFSY (the 'personal menu' option shown in Fig. 2);
- using a fourth-generation interrogation language that allows easy use of data stored in different files, the final choice being AS (Application System), a European product from IBM's Warwick Laboratory (UK); its possibilities have grown, from one version to the next, in step with the Agency's IBM operating environment (at the time of writing, AS

Version 1.5.1 is used for the whole of the EFSY reporting system);

- creating 'batch input points', so that EFSY can interface with external electronic data files coming from other systems either inside or outside the Agency. This facility, used in parallel with current operations, is becoming more and more important, since there is a general trend towards increased electronic linking of related systems with EFSY. EFSY has been thrust into an increasingly central role for the collection and processing of system-transferred, rather than hand-entered data, and this evolution is still gathering pace.

Stages in the project

The 'service bureau' period

After a great deal of work to standardise procedures so that they could be applied in all of the Agency's Establishments, EFSY was put into operation for the first time at the beginning of 1984. The software and database were installed at IBM's operational centre in Zoetermeer (NL). All users were linked to the centre through IBM's international network (IPCS), with each ESA Establishment connected to the nearest local input point on the network via a PTT line.

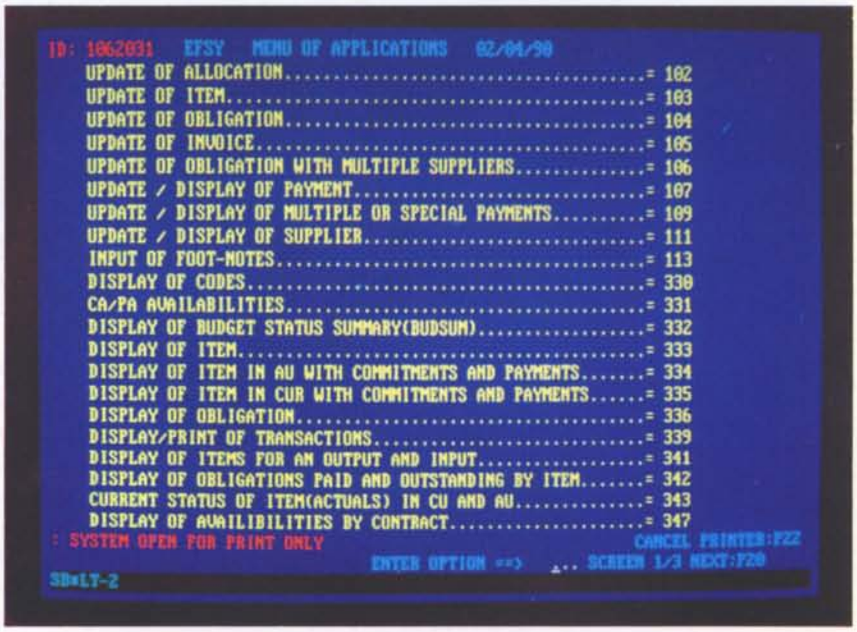
In the first five months of operation, it was possible not only to check that the software was working well, but also to gauge accurately the amount of resources being used. The essential facts and figures on hours of use of the central processing unit, connect time, use of mass memory and printer time, and main-function response time were collated to serve as a basis for estimating the annual cost of using the IBM Service Bureau. The Agency subsequently signed a two-year contract with IBM, to run from 1 June 1984.

Bringing the system in-house

The service bureau arrangement was not intended to last indefinitely. Apart from the fact that some critical data were being stored outside the Agency under this arrangement, operating costs were much higher than those of an equivalent in-house configuration.

The Executive began looking seriously at the idea of bringing EFSY in-house towards the end of 1984. The actual go-ahead for the in-house project was given in March 1985, after IBM announced that it would be marketing the MVS*/AS product that was essential for running EFSY away from its Service Bureau.

In the course of 1985, the methodology for converting EFSY to an in-house machine was worked out and the 'tools' needed for the task prepared. In January 1986 an IBM 4381 was commissioned at ESA Headquarters, and in February that year the first suite of EFSY programs was converted and tested. The switchover of EFSY operations from Zoetermeer to the Agency's in-house configuration was successfully completed on 28 May 1986, three days before the expiry of the external service contract.



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    UPDATE OF INVOICE.........................................= 105
    UPDATE OF OBLIGATION WITH MULTIPLE SUPPLIERS..............= 106
    UPDATE / DISPLAY OF PAYMENT...............................= 107
    UPDATE / DISPLAY OF MULTIPLE OR SPECIAL PAYMENTS..........= 109
    UPDATE / DISPLAY OF SUPPLIER..............................= 111
    INPUT OF FOOT-NOTES.......................................= 113
    DISPLAY OF CODES..........................................= 330
    CA/PA AVAILABILITIES......................................= 331
    DISPLAY OF BUDGET STATUS SUMMARY(BUDSUM)..................= 332
    DISPLAY OF ITEM...........................................= 333
    DISPLAY OF ITEM IN AU WITH COMMITMENTS AND PAYMENTS.......= 334
    DISPLAY OF ITEM IN CUR WITH COMMITMENTS AND PAYMENTS......= 335
    DISPLAY OF OBLIGATION.....................................= 336
    DISPLAY/PRINT OF TRANSACTIONS.............................= 339
    DISPLAY OF ITEMS FOR AN OUTPUT AND INPUT..................= 341
    DISPLAY OF OBLIGATIONS PAID AND OUTSTANDING BY ITEM.......= 342
    CURRENT STATUS OF ITEM(ACTUALS) IN CU AND AU..............= 343
    DISPLAY OF AVAILIBILITIES BY CONTRACT.....................= 347
: SYSTEM OPEN FOR PRINT ONLY                                     CANCEL PRINTER:F22
                           ENTER OPTION ==>   ... SCREEN 1/3 NEXT:F20
SB*LY-2
```

Figure 2. Example of an EFSY menu

EFSY today

Software

EFSY is a basic working tool for ESA's Finance Department. It has gradually been extended to cover nearly all the work done by this Department in respect of the ESA Financial Regulations (Fig. 3), including:

- following-up the current year's budget;
- preparing and updating the budget for the coming year;
- preparing and proposing carry-overs of funds;
- preparing payment forecasts;
- recording commitments, payments, financial transactions and recharges;
- consolidating financial and budget accounts and recharges at ESA level;
- processing call-ups and receipts of Member-State contributions;
- managing inventories;
- managing travel costs;
- updating the annual budget forecasts in line with price trends;

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* Multiple Virtual Storage

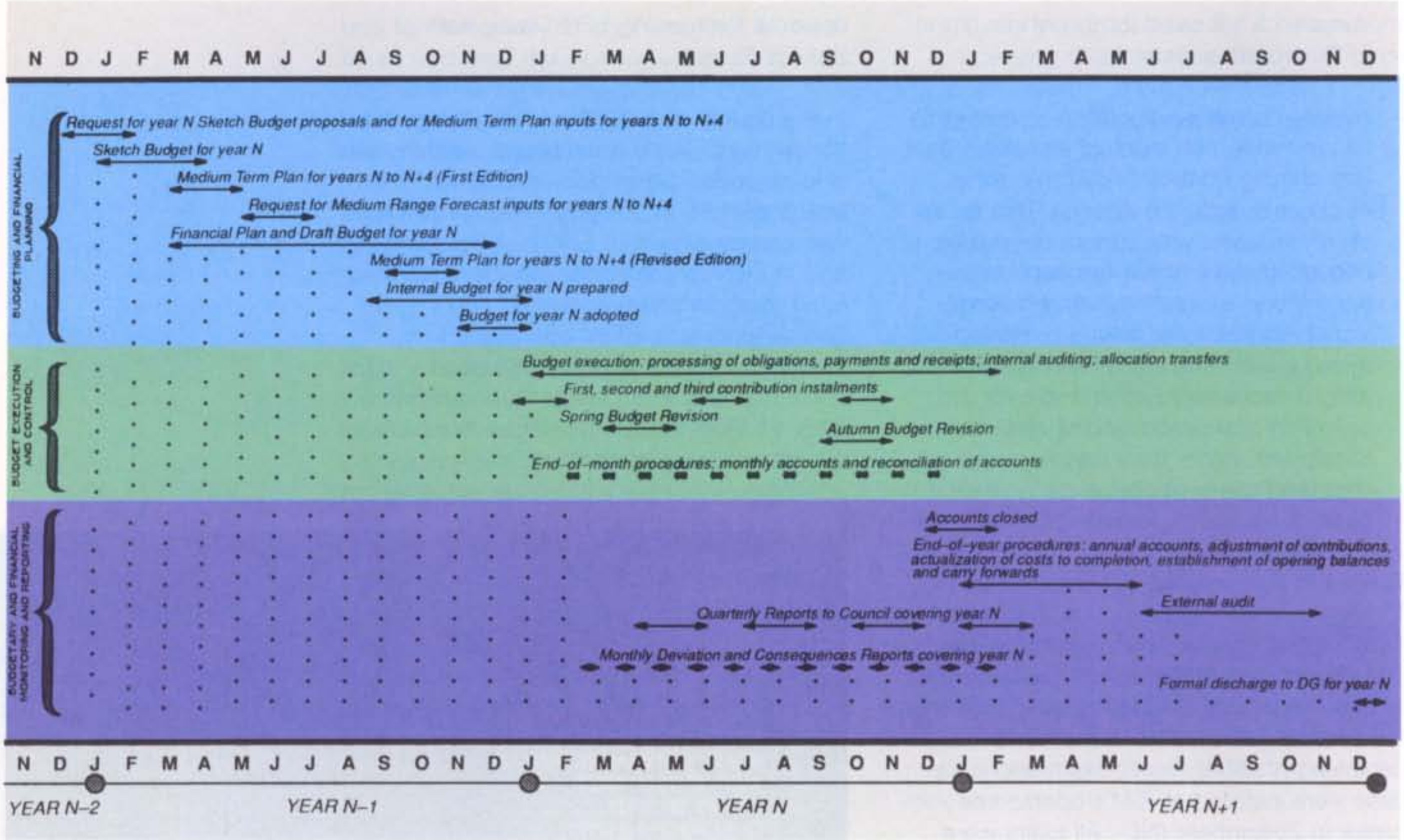


Figure 3. Schedule of financial events for a sample year 'N' (taken from the EFSY User's Manual)

- backdating the cost-to-completion of programmes;
- closing the annual accounts.

EFSY is a true multi-user system, with every user able to request access to the same data at any given moment. The system is fully integrated in the sense that any item of data inputted to one file will immediately be incorporated automatically into other associated files, thereby avoiding any need for multiple-point data entry. Consequently, it has been possible with EFSY to reduce the time needed to consolidate the Agency's monthly accounts to less than an hour. The EFSY interrogation and printout programs can thus produce an accurate, up-to-the minute picture of ESA's financial situation, on demand, within the hour.

Access to EFSY

By May 1987, an ever-increasing work load (currently more than 70 different program budgets) and an expanding user community dictated the transfer of the EFSY software from the Headquarters machine to a much larger computer at ESOC in Darmstadt. As the Agency's Operations Centre, ESOC offers a round-the-clock service, and also has the expert knowledge of the MVS system essential for supporting EFSY. Today, all EFSY users (currently about 100, rising to 150 by the end of this year) are linked to ESOC via the ESANET network.

Interfaces

For several years the use of EFSY was restricted to members of the Agency's Finance Department. During the 'service bureau era', the main constraint was one of cost. After the system was brought in-house and then transferred to ESOC, a period of 'operational stability' was imperative for evaluating its performance. At the end of 1987, however, things moved forward again:

(a) It was made possible to bring files derived from other software systems into EFSY automatically, via 'batch-input points', including:

- electronic invoices coming from ESA's Tele-Invoicing System (ETIS), operated by Finance in ESTEC;
- the system shared by Contracts Department and ESTEC for budget/contract planning (ESCA);
- the payroll results (GIP, or Gestion Integrée du Personnel);
- accounting figures from CNES (this will be operational by the end of March 1990); and
- data for firms, which the Industrial Policy Office has to supply to the Member States.

This batch interface can be used to incorporate files into EFSY at any time without a break in service. It is even possible to integrate several files at the same time from different points in the ESA network.

(b) EFSY constitutes a single source of accounting data for the Agency as a whole. As office automation developed, the need to be able to look at financial data in electronic rather than paper form became more and more acute. The number of EFSY data-extraction programs was therefore increased from 1988 onwards, covering in particular the tasks of:

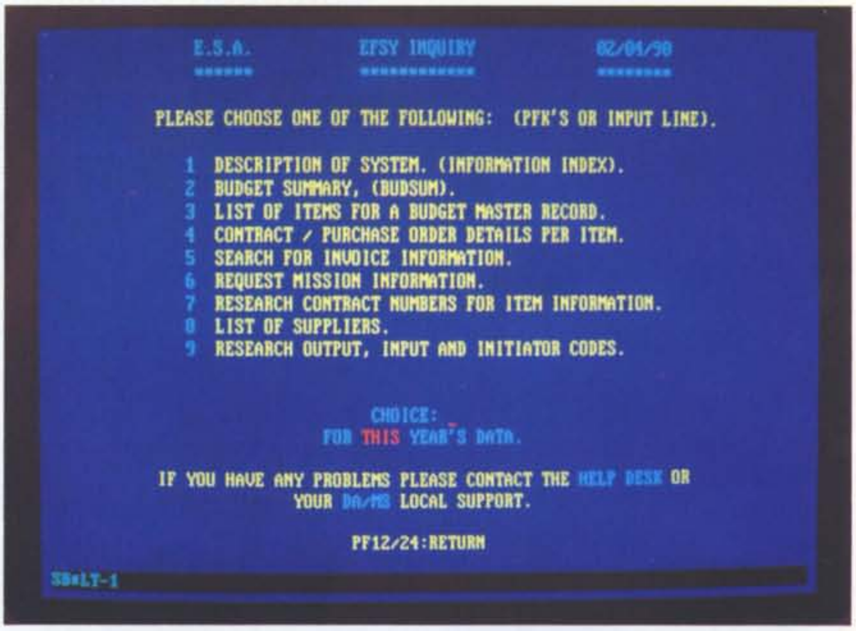
- extracting contract commitments for the purpose of calculating geographical return; and
- extracting financial statements which are never more than 24 h old for viewing via the PROFS system (Fig. 4).

Outlook

Aside from regular maintenance of the software and constant enhancements to it, analysis and development effort is currently being focused in three directions. The first is to take account of international standards in all the links EFSY has with the world of industry. Examples are the ISO standards 4217 and 3166 for currency codes and country codes, and the EDIFACT** standard for tele-invoicing; the latter, developed under the aegis of the United Nations (UN Standard Electronic Invoice Message) will be made available (as a complement to ETIS) within EFSY this year.

The second is linked to rapid growth in the use of networked PCs, with more and more staff members wishing to use them to access the central database on the mainframe computer. The Management Systems Office will therefore be providing these users with the facilities and procedures necessary to extract data easily from EFSY and download them onto their PC.

Finally, there is the financial database itself, the present structure of which (using VSAM*** files) could be profitably replaced by a relational database (RDB). The technology is progressing quickly in this area, and quite a few software houses are making RDBs their primary product for the years ahead. But while these relational databases do have their advantages, they are also well-known for performing poorly when there are large numbers of users, if not carefully implemented. ESA is therefore pursuing a cautious step-by-step approach.



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        E.S.A.              EFSY INQUIRY              02/04/90
        ******              ************              ********

   PLEASE CHOOSE ONE OF THE FOLLOWING:  (PFK'S OR INPUT LINE).

        1  DESCRIPTION OF SYSTEM. (INFORMATION INDEX).
        2  BUDGET SUMMARY, (BUDSUM).
        3  LIST OF ITEMS FOR A BUDGET MASTER RECORD.
        4  CONTRACT / PURCHASE ORDER DETAILS PER ITEM.
        5  SEARCH FOR INVOICE INFORMATION.
        6  REQUEST MISSION INFORMATION.
        7  RESEARCH CONTRACT NUMBERS FOR ITEM INFORMATION.
        8  LIST OF SUPPLIERS.
        9  RESEARCH OUTPUT, INPUT AND INITIATOR CODES.


                          CHOICE: _
                   FOR THIS YEAR'S DATA.

   IF YOU HAVE ANY PROBLEMS PLEASE CONTACT THE HELP DESK OR
                  YOUR DA/MS LOCAL SUPPORT.

                      PF12/24:RETURN
SB*LT-1
```

Figure 4. The EFSY/PROFS menu, PROFS being the IBM Professional Office System product (for office-automation) in use throughout ESA

Conclusion

Given that the Agency's three new large programmes, Ariane-5, Hermes and Columbus, are now getting fully underway, one must anticipate a drastic increase in the annual number of financial transactions to be made. This in turn will invariably put a corresponding load on the administrative machinery, a challenge that Finance Department should be well placed to meet with the help of the powerful yet flexible EFSY package now in place.

** Electronic Data Inter-change for Administration, Commerce and Transport

*** Virtual Storage Access Method

In brief

ESA/USSR Cooperative Agreement

An agreement on cooperation in the exploration and use of space for peaceful purposes between the Government of the Soviet Union and ESA was signed on 25 April at ESA Headquarters in Paris, by the Soviet Union's Ambassador, His Excellency Iakov Riabov, and the Agency's Director General, Prof. Reimar Lüst.

The Agreement is for an initial period of ten years and covers a wide range of space activities, including: exploration of the Solar System, space astronomy and astrophysics, Earth observation and meteorology and life sciences. Working groups will be established for each of these disciplines, to investigate and recommend potential cooperative projects.

ESA has a long history of scientific cooperation with the Soviet Union, the formal basis of which has until now been an Exchange of Letters between the Soviet Academy of Sciences and ESRO (one of ESA's forerunners), largely concerned with the exchange of scientific information. One of the most spectacular of past cooperative ventures was the encounter with Halley's Comet in 1986 by ESA's Giotto, two Soviet spacecraft, Vega-1 and -2, as well as two Japanese spacecraft. Amongst other joint projects, ESA experiments were flown aboard the Soviet space biology missions, Biokosmos-8 and -9 in 1987 and 1989.

In February this year an International Workshop was held in Graz, Austria, to discuss the scientific aspects of cooperation between ESA's Cluster project and the Soviet Regatta mission.

His Excellency Iakov Riabov, Ambassador of the Soviet Union (left) and Prof. Reimar Lüst (Paris, 25 April)

Mr J-M. Luton Appointed Director General

On 14 February the ESA Council appointed Mr Jean-Marie Luton to the post of Director General for the period 1 October 1990 – 30 September 1994, succeeding Prof. R. Lüst.

Mr Luton is currently Director General of CNES, the French national centre for space studies. A graduate of the Ecole Polytechnique, Mr Luton was engaged in research in external geophysics at the French National Centre for Scientific Research, CNRS, from 1964 to 1971.

From 1971 to 1973 he was seconded to the Ministry of Industrial and Scientific Development, playing an active role in France's space policy and in the European negotiations that led to the establishment of ESA.

Mr Luton joined CNES in 1974 and is the CNES representative on the Arianespace Board of Directors. In May 1987 he joined Aerospatiale and became Director of Space Programmes in the Department of Space and Strategic Systems.

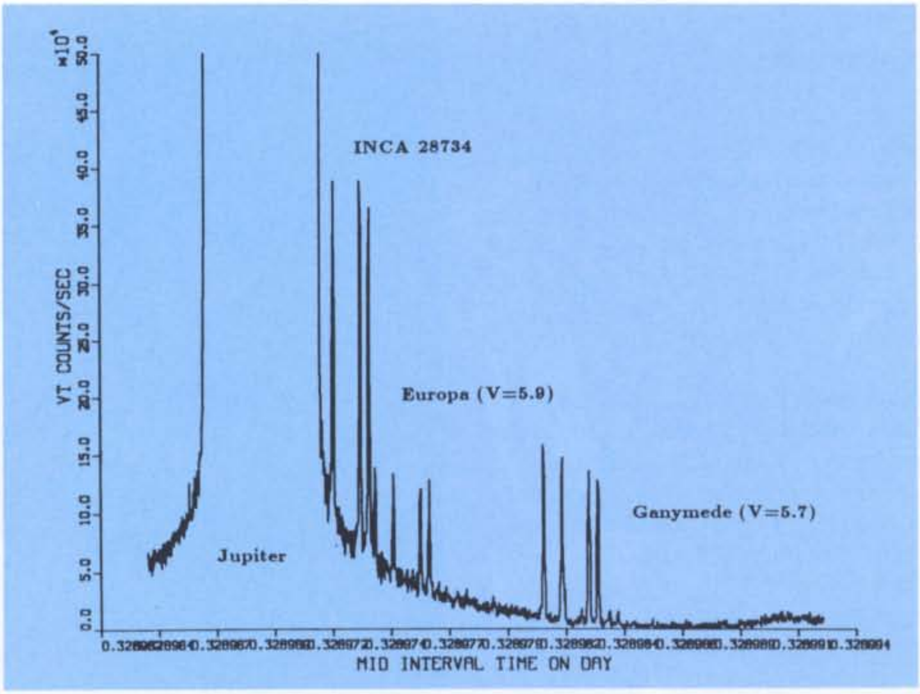
He is currently a French delegate to the ESA Council, and also chaired the Agency's Administrative and Finance Committee from 1 July 1984 to 30 June 1987.

Hipparcos Survives Solar Eclipse

Soon after Hipparcos became trapped in its highly elliptical orbit, the operations team realised that a critical test of the satellite's power system would occur around mid-March, when the satellite would have to endure extended periods of solar eclipse.

For three weeks the solar arrays were in shadow for a much longer period each day than the 72 minutes foreseen in the nominal circular orbit. During these eclipses, the spacecraft had to rely solely on battery power.

Prior to the maximum eclipse period, about 105 minutes on 16 March, contingency plans were put into action at ESOC to shut down elements of the payload to limit the drain on the batteries. The satellite survived this critical event with a power margin of barely five minutes and scientific measurements were able to proceed without interruption.



The fourth ground station, the NASA Goldstone station in the Mohave desert in California, is now on line, increasing the amount of scientific data that can be retrieved from the satellite.

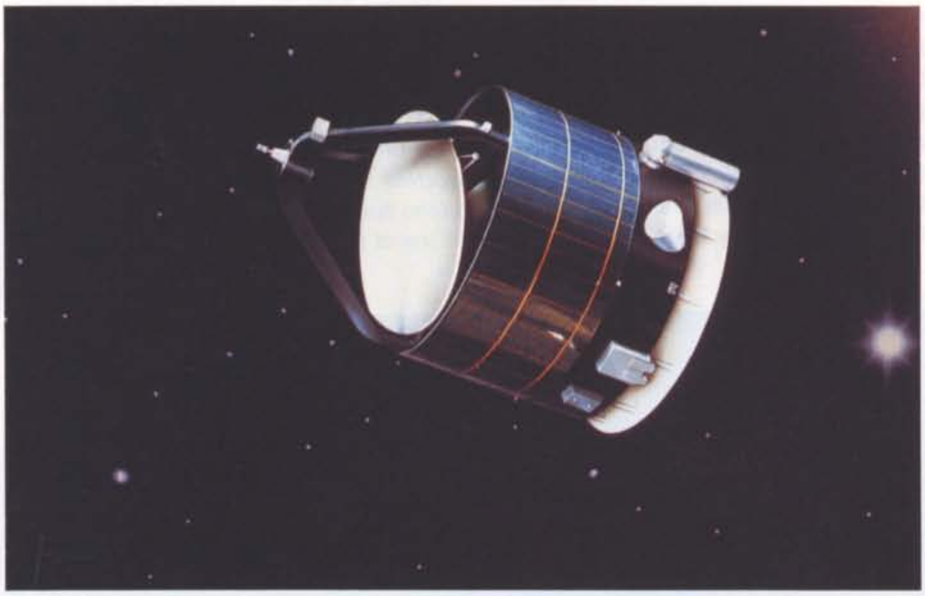
Passage of Jupiter and its moons Europa and Ganymede across the Hipparcos star mapper slits, 13 March 1990

Giotto Reactivated

On 19 February 1990 a faintly whispered radio signal was received at the Madrid tracking station of NASA's Deep Space Network. The signal was from Giotto, the ESA probe that has been hibernating in deep space since its spectacular encounter with Halley's comet in March 1986.

Preparations have been underway since May 1988 at the Agency's Operations Centre (ESOC) in Darmstadt, Germany, to reactivate the spacecraft. Beginning on 19 February, a series of telecommands was transmitted to Giotto via the Madrid tracking station, using a 70 m antenna and a 100 000 Watt transmitter, many thousand times the power of a TV broadcasting station. The first faint reply was received when Giotto was about a hundred million kilometres from Earth.

The mission-control team at ESOC then performed a series of complex manoeuvres to point Giotto's high-gain antenna towards the Earth in order to increase the strength of the signals, so that a complete check-out of the spacecraft could be performed.



The first of a series of manoeuvres to target Giotto for its new mission, an encounter with comet Grigg-Skjellerup, was performed in mid-March. Giotto was then 75 million km from Earth. The temperature of the spacecraft was found to be too high, because of damage to the thermal insulation and thermal surfaces during the Halley encounter. However, as Giotto moves further from the Sun, the spacecraft should cool down, and checking-out of the scientific instruments can begin, from end-April onwards. In the meantime periodic orbit-control manoeuvres are being performed.

On 2 July 1990 Giotto will pass within 23 000 km of Earth, and the Earth's gravitational field will be used as a 'sling-shot' force to propel the spacecraft on towards its new target.

Hubble Space Telescope Launched

The NASA/ESA Hubble Space Telescope (HST) was launched from Cape Canaveral on 24 April by the Space Shuttle Discovery. Two weeks earlier, on 10 April, because of a defective valve in the Shuttle's hydraulic system, the countdown had been stopped four minutes before launch.

Starting 4½ hours after the successful launch, the Shuttle crew initiated Orbiter power to operate the Telescope, and ground controllers at NASA's Goddard Space Flight Center (GSFC) spent the next 19 hours activating its communications systems, thermal controls, other onboard systems and scientific instruments. Mission Specialist Steven Hawley then operated the Orbiter's remote manipulator arm to lift HST out of the payload bay. At this point the supply of power from the Orbiter was disconnected and the Telescope became reliant on its own battery power.

Once HST was out of the payload bay and correctly oriented, ESA controllers at GSFC could intitiate deployment of the ESA-provided solar arrays, which had been rolled up and hinged back against the body of the Telescope during the launch. Within 7 hours, after some minor anomalies, the arrays were completely unfurled and fully operational, recharging the Telescope's batteries. A margin of 8 hours had originally been allowed for the deployment operation. In the event, the body of the Telescope was significantly hotter than expected so there was far less drain on the batteries in terms of heater power. This, in combination with the high level of battery power available, meant that the time available for deployment was in practice much less constrained than predicted.

The arrays, 2.8 m wide, 12 m in length and each containing 24 380 solar cells, will provide HST with at least 4.4 kW of power for the first four years (twice the time specified for this level of power). One of the most interesting features of the array design is their unique capability for in-orbit replacement. This will occur at least once during HST's 15-year lifetime. A full description of the arrays, built for ESA by British Aerospace, is contained in Bulletin 61, pages 13 – 19. The preceding article (pp. 9 – 11) in that issue describes the history of ESA's involvement in the Hubble Space Telescope.

ESA's Faint Object Camera (FOC), which constitutes the other main element of Europe's 15% contribution to HST, will be switched on by the end of May. The FOC will extend the reach of the HST to its greatest possible distance and produce its sharpest images. It will photograph stars five times further away than is possible with ground-based telescopes.

Photo: NASA

The Hubble Space Telescope after deployment from Space Shuttle 'Discovery'

Photo: NASA

The Hubble Space Telescope suspended in space from Space Shuttle Discovery's remote manipulator system, with one of the ESA-provided roll-out solar panels, yet to be deployed, in the foreground

American Vice-President Dan Quayle Visits ESA Headquarters

The Vice-President of the United States, Mr Dan Quayle, in his capacity as Chairman of the White House's National Space Council, paid a visit to ESA Headquarters on 9 May.

During his visit, Mr Quayle met Professor Lüst, the Agency's Director General, to discuss cooperation between ESA and the United States, with particular regard to the International Space Station Freedom. The discussions also included possible European participation in the 'Space Exploration Initiative', the proposal by President Bush to undertake manned missions to the Moon and Mars, and Europe's contribution to the international effort to preserve the Earth's environment.

The visit was particularly timely in the light of the recent launch of the NASA/ESA Hubble Space Telescope and the forthcoming Ulysses launch. Future ESA/NASA cooperative ventures include the Soho/Cluster and Huygens/Cassini missions.

Prof. Reimar Lüst, ESA's outgoing Director General, introducing his successor, Mr Jean-Marie Luton, to Mr Dan Quayle, Vice-President of the United States (ESA Headquarters, 9 May)

Photographer: S. Vermeer, ESA

Mr and Mrs Dan Quayle

Ariane V36 Board of Enquiry

Immediately after the failure of the Ariane V36 flight on 22 February, ESA and Arianespace appointed an enquiry board composed of independent experts. The mandate of the board was to establish the reasons for the failure and to recommend the necessary corrective measures. The board submitted its report to ESA and Arianespace at the end of March.

On 9 April a joint press conference was given by the Chairman of Arianespace, Mr F. D'Allest, and ESA's Director of Space Transportation Systems, Mr J. Feustel-Büechl, together with Mr J. Durand, the Chairman of the enquiry board. In its report, the board drew four main conclusions:

- The mission failed because of a drop in thrust in one of the four first-stage Viking-V engines. This occurred 6.2 seconds after a normal start-up of the engines and launcher liftoff. It was caused by a near-total blockage in the circuit supplying water to Viking engine D, which itself operated correctly. The blockage occurred immediately upstream of the engine, before the water pump. The precise cause of the blockage was either the untimely presence of a foreign body in the water circuit or a defect in the main water valve, although the enquiry board considered the latter less probable.
- In addition, there was another anomaly 2.4 seconds after ignition of the engines, in the propulsion bay of one of the four liquid boosters (No. 3). A leak in the N_2O_4 oxidiser led to a fire breaking out in the presence of a slight leak of UH_{25} fuel.
- Having conducted an investigation, the enquiry board did not find any correlation between these two incidents.
- The loss of the flight 36 mission does not invalidate the design of the Ariane-4 launcher.

The enquiry board has made 44 specific recommendations, all of which have been accepted by Arianespace and ESA. Of these, nine are major recommendations which must be applied before authorisation to proceed with flight 37. They involve tightening up the procedures and checks applied, rather than major changes to the launcher elements. They are concerned mainly with the procedures for integrating the first and second stages with the liquid-propellant booster fluid circuits and verifying leak-tightness.

Having analysed the recommendations, the Ariane Steering Committee, together with ESA and the industrial firms concerned, Aerospatiale (F), MBB/Erno (D) and SEP (F), has drawn up a list of corrective actions. These include:

- continuation of the recovery operations. So far, the main part of the propulsion bay of liquid booster No. 3, a large section of the Engine-D water-supply circuit and the first-stage water-tank-outlet filter have been recovered. The first-stage propulsion bay with the four Viking-V engines has been located, but conditions at the site are making recovery extremely difficult;
- inspection, by independent laboratories, of the hardware recovered;
- detailed definition of the modified procedures, in particular those relating to integration and checking of the fluid circuits;
- measures to improve the reliability of the elements concerned.

The Ariane launch programme has been on hold pending the results of the enquiry. On the basis of the report and the corrective actions already underway, Arianespace estimates that it will be able to resume launches this summer.

Establishment of the European Astronaut Centre in Cologne

Formal signature of the Agreement between the Agency and the Federal Republic of Germany on the establishment of the European Astronaut Centre (EAC) in Porz-Wahn, Cologne, took place on 10 May, in Cologne.

The Agreement was signed on behalf of the host country by the Secretary of State Mr H-W. Lautenschläger, representing Mr Hans Dietrich Genscher, Minister of Foreign affairs, and Dr Heinz Riesenhuber, Federal Minister for Research and Technnology, and on ESA's behalf by the Director General, Prof. Reimar Lüst.

The EAC will be dedicated to the selection, recruitment and training of European astronauts. With construction work beginning at the end of 1991, the Centre is scheduled to open in 1993. Under the policy on European astronauts, approved last year, there will be a single European astronauts' corps, with at least one national from each Member State. The Member States will therefore conduct pre-selection exercises and ESA will be responsible for the final selection. The Announcement of Opportunity for recruitment will be released shortly.

Although EAC will have overall responsibility for astronaut training, it will be supported by a number of specialised training facilities all over Europe.

In this context, following the EAC Host Agreement ceremony, a Service Agreement between ESA and the German Aerospace Research

Meteosat-4 Tests Completed

In January, Meteosat-4 operations were temporarily switched over to Meteosat-3 to allow investigation of some minor anomalies that have been detected recently in the Meteosat-4 image. Meteosat-4 has now resumed its role as prime satellite and a report on the test campaign will be submitted to Eumetsat by the end of May.

Meteosat-4, Europe's first operational meteorological satellite, was launched in March 1989 and is operated by ESA on behalf of Eumetsat. Meteosat-3 was the last of a series of pre-operational satellites developed and owned by ESA, launched principally as a stop-gap mission prior to the start of the operational campaign. The recent incident has served to demonstrate its value as a back-up, in that the test campaign could be conducted without interruption of the Meteosat service.

Establishment (DLR) was signed by Prof. Lüst and Prof. W. Kroll, Chairman of the Board of DLR. Existing facilities at DLR are being expanded to create a training complex (CTC), which will include full-scale mock-ups and system simulators of the Attached Laboratory, Free-Flying Laboratory, Hermes, etc. and a neutral buoyancy facility.

Other facilities in the European-astronaut training infrastructure include the Hermes training complex in Toulouse for Hermes-specific training and the pilot-training facility in Brussels. Extra-vehicular (EVA) training will take place in the COMEX facilities in Marseilles, while robotics and remote-manipulation training activities will be conducted in the new robotics laboratory in ESTEC.

Photos: DLR

Signing of the Agreement on the establishment of the European Astronaut Centre (EAC) in Cologne. Above, seated left to right: Secretary of State, Mr H-W. Lautenschläger, Dr Heinz Riesenhuber, Federal Minister for Research and Technology and Prof. Reimar Lüst, ESA's Director General (Cologne, 10 May)

Prof. W. Kroll, Chairman of the Board of the German Aerospace Research Establishment (DLR) and Prof. R. Lüst sign the Service Agreement between ESA and DLR

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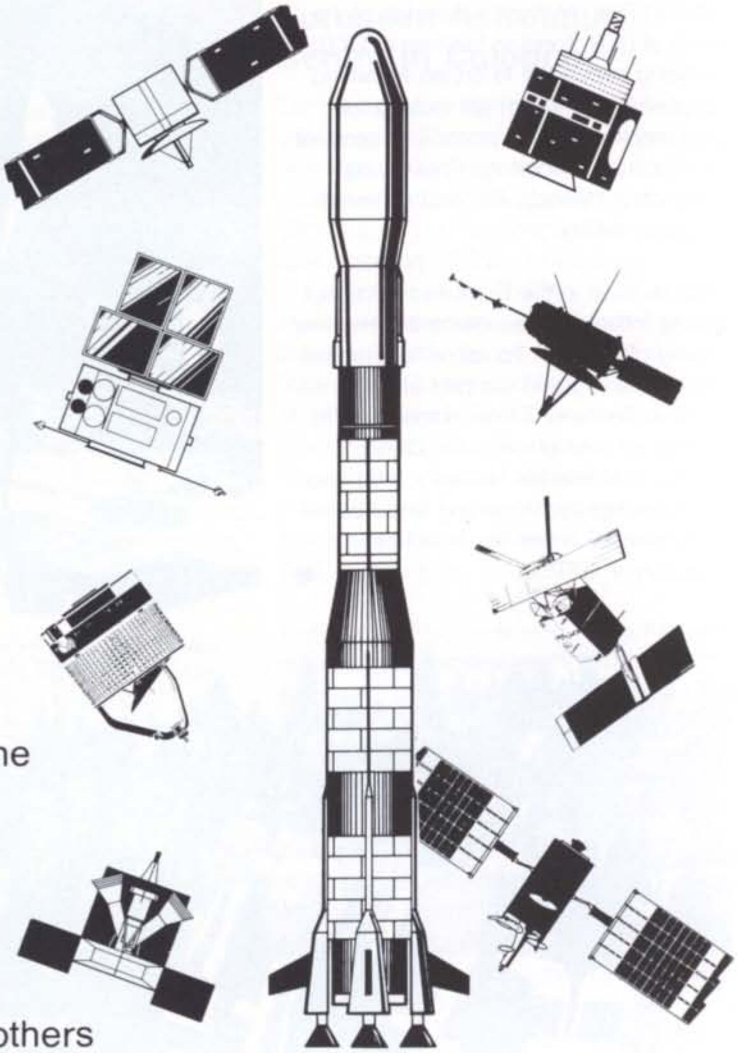

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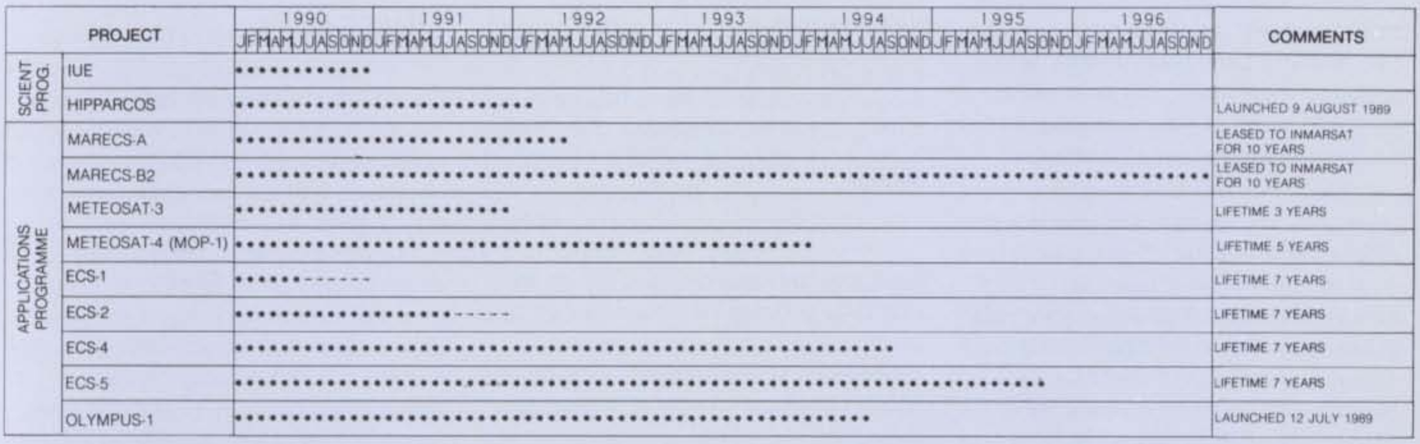
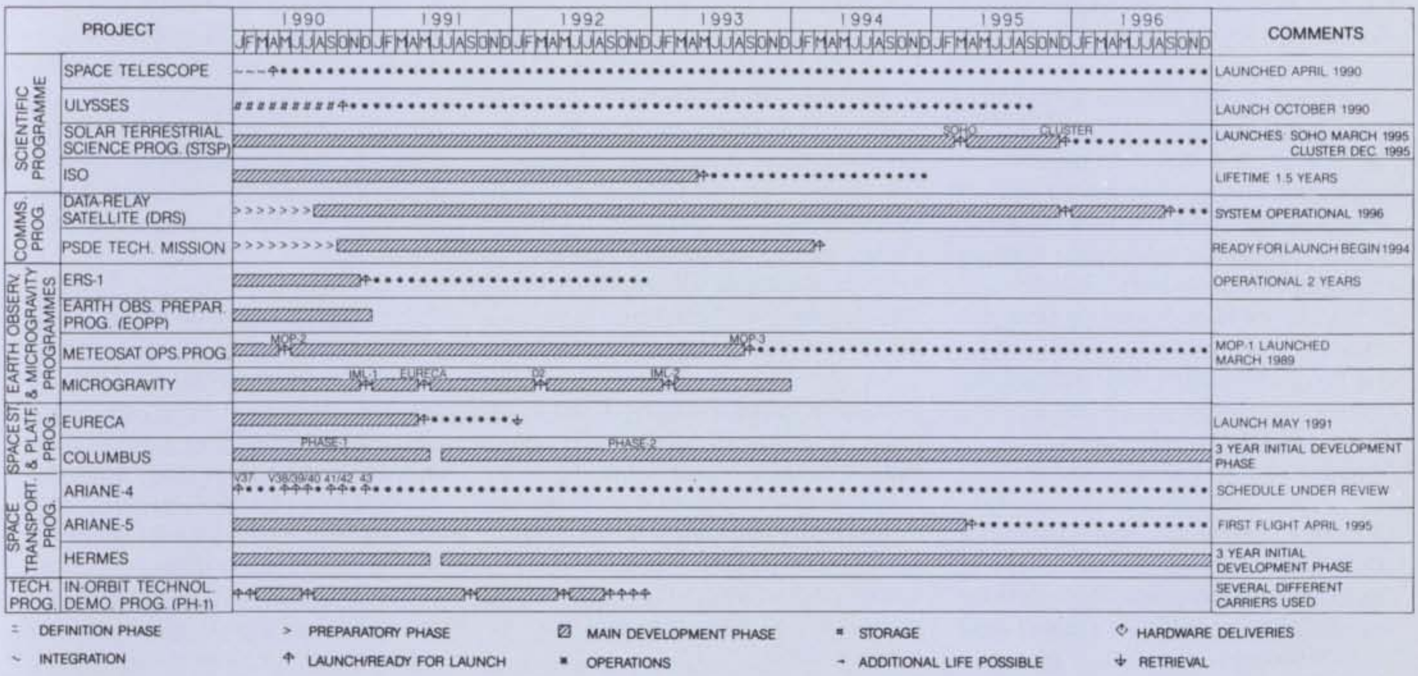
Programmes under Development and Operations / Programmes en cours de réalisation et d'exploitation

In Orbit / En orbite



Under Development / En cours de réalisation



Olympus

La phase du lancement et du début de fonctionnement en orbite (couvert par l'assurance) du satellite Olympus-1 s'est achevée le 7 janvier après le bon déroulement des 180 premiers jours d'exploitation. Le Centre de contrôle des opérations de Fucino, en Italie, assure sans problème la conduite des opérations du satellite. La plate-forme et les charges utiles d'Olympus-1 poursuivent leur bon fonctionnement en orbite.

L'utilisation des charges utiles de télévision directe, des services spécialisés et de télécommunications à 20/30 GHz se déroule à un rythme rapide avec l'installation de terminaux au sol en nombre croissant. Les charges utiles présentent des caractéristiques de fonctionnement supérieures aux spécifications dans presque tous les secteurs, notamment pour la puissance rayonnée, la sensibilité de réception et la couverture assurée par les antennes.

La charge utile de diffusion directe est utilisée par la BBC et l'organisme d'utilisateurs Eurostep pour des émissions quotidiennes s'appuyant pour la liaison montante principale sur la station terrienne TDS-5 de l'ESA de Silwood Park, près de Londres. La British Telecom International (BTI) procède également chaque jour à des essais de 'diffusion sélective' (transmission de données unidirectionnelle), tandis que la RAI italienne a commencé à utiliser le faisceau italien via sa station de liaison montante de Rome.

La charge utile des services spécialisés a permis de faire la démonstration de l'accès multiple à répartition dans le temps avec commutation à bord du satellite (AMRT-CS) à l'occasion d'une vidéoconférence bidirectionnelle entre établissements de la British Telecom (BT). L'Université technique de Graz a expérimenté avec succès l'AMRT, tandis que Polytechnic South-West poursuit des émissions régulières depuis son studio de télévision de Plymouth, au sud de l'Angleterre.

La charge utile de télécommunications à 20/30 GHz a été utilisée pour l'expérience de communications directes inter-établissements (DICE). Celle-ci avait été initialement prévue pour le seul Royaume-Uni mais on envisage de lui donner une dimension internationale. Les contrats relatifs à l'expérience en coopération sur les données d'Olympus (CODE) progressent conformément au calendrier.

Parmi les autres utilisateurs de la charge utile on citera le Département canadien des communications et l'administration des PTT (FTZ) de la République fédérale d'Allemagne.

La charge utile de propagation est suivie en permanence depuis douze emplacements différents, et de façon intermittente par d'autres utilisateurs.

Le Secrétariat pour l'utilisation d'Olympus (OPUS) de l'ESTEC assure l'interface avec les utilisateurs d'Olympus et l'établissement du schéma du programme d'exploitation du satellite.

Le satellite est situé comme TDF-1 à 19° ouest, le satellite TV Sat-2 se trouvant quant à lui à 19,2° ouest. Les manoeuvres de maintien à poste de ces satellites sont étroitement coordonnées en attendant qu'une stratégie à long terme soit mise au point pour le contrôle de satellites multiples occupant une même position.

Ulysses' press conference, ESTEC (NL), November 1989. From left to right: Mr D. Dale, Head of Scientific Programmes; Prof. R. Bonnet, Director of Scientific Programmes; Mr M. Le Fèvre, Director of ESTEC; Dr K-P. Wenzel, Ulysses' ESA Project Scientist and Mr D. Eaton, Ulysses' Project Manager.

Ulysse

Ulysse a franchi une nouvelle étape lorsque début février le modèle de vol du satellite a achevé le cycle des essais destinés à prouver qu'il est toujours apte au vol après les nombreux reports et temps de stockage subis. Tous les essais ont donné satisfaction et malgré quelques problèmes mineurs, normaux dans une phase d'essais intensifs, aucune difficulté notable n'a été rencontrée. Les 12 et 13 février il a été procédé à une revue officielle avant expédition devant une commission mixte composée de hauts représentants de l'ESA, du JPL et de la NASA. Ceux-ci ont confirmé à l'unanimité que le véhicule spatial était bon pour le vol et en ont approuvé le transport au Centre spatial Kennedy (KSC) en mai 1990, en vue de la préparation de son lancement le 5 octobre. A l'heure actuelle, le véhicule spatial se retrouve à nouveau entreposé dans son conteneur spécial puisqu'il n'a pas été nécessaire d'utiliser même en partie la marge de sécurité inscrite dans le planning.

Tout se déroule également bien à l'ESOC, d'où sera assurée la conduite des opérations du véhicule spatial après son lancement. Le 9 février, la commission mixte ESA/JPL/NASA a fait le point de la situation pour l'ensemble des opérations postérieures au lancement et a en particulier autorisé l'expédition du système de contrôle de la mission d'Ulysse (UMCS) de l'ESOC, qui assurera la commande et le contrôle du véhicule spatial à partir du moment où il

Olympus

The launch and in-orbit insurance period of Olympus-1 ended on 7 January after the satisfactory completion of the first 180 days of operations. Control of the satellite from the operations control centre at Fucino in Italy is proceeding smoothly. The platform and payloads of the Olympus-1 satellite continue to work well in orbit.

Use of the TV Broadcast, Specialised Services and 20/30 GHz Communications payloads is increasing quickly, with the installation of more ground terminals. The performance of the payloads has been better than specified in nearly all areas, particularly in terms of radiated power, receiver sensitivity and antenna coverage.

The Direct Broadcast payload has been used by the British Broadcasting Corporation (BBC) and the user's organisation, Eurostep, for daily transmissions using the ESA TDS-5 earth station located at Silwood Park, near London, as the prime uplink. British Telecom International (BTI) has also been performing daily test transmissions of 'Narrowcasting' (one-way data transmission), while the the Italian Broadcasting Corporation, RAI, have started broadcasting on the Italian beam, using their uplink station in Rome.

The Specialised Services payload has been used to demonstrate Satellite-Switched Time Division Multiple Access (SS-TDMA) when a two-way video conference was set up between British Telecom (BT) establishments. The Technical University of Graz has successfully performed TDMA experiments, while the Polytechnic of the South-West continues to make regular transmissions from its TV studio in Plymouth, England.

The 20/30 GHz communications payload has been used for the Direct Inter-establishment Communications Experiment (DICE). DICE was originally scheduled solely for the UK but wider international usage is now being considered. Contracts for the Cooperative Olympus Data Experiment (CODE) are progressing on schedule. Other users of the payload have included the Canadian Department of Communications and the Deutsche Bundespost, FTZ.

The propagation payload is being monitored on a continuous basis from twelve locations and also by other users intermittently.

The Olympus Utilisation Secretariat (OPUS) at ESTEC continues to provide the interface with the users of Olympus and to outline the satellite's operations schedule.

The satellite is located at 19°W with TDF-1, while TV Sat-2 is at 19.2°W. The station-keeping manoeuvres of these satellites are being closely coordinated until the long-term strategy for control of multiple satellites at the same location is complete.

Ulysses

Yet another major milestone was achieved for Ulysses when in early February the flight spacecraft completed its cycle of testing to prove that it was still flightworthy after the numerous delays and storage periods. All of the tests were successful and, although there were a few minor problems, as normal during intensive testing, no major difficulties were encountered. On 12 – 13 February a formal pre-shipment review was held before a joint board, composed of senior ESA, JPL and NASA representatives. They unanimously confirmed the spacecraft acceptability for flight and gave approval for its transport to Kennedy Space Center (KSC) in May 1990 to prepare for launch on 5 October. At the present time the spacecraft is once again in its storage container, since none of the buffer period built into the planning needed to be used.

In ESOC, from where the spacecraft will be controlled after launch, preparations are going smoothly. On 9 February the joint ESA/JPL/NASA board also reviewed the status of the complete post-launch operations for Ulysses and, in particular, authorised the shipment of the ESOC Ulysses Mission Control System (UMCS), which controls and monitors the spacecraft from separation from the Upper Stage onwards. The UMCS has now been installed in the Control Centre at JPL where compatibility tests with the JPL and Deep-Space Networks (DSN) systems are proceeding well.

An equally satisfactory status exists for the Upper Stage. The Inertial Upper Stage (IUS) is already at KSC where preliminary work is being carried out prior to a short period of storage introduced for logistical reasons. The PAM-S is now also at KSC and being mated with its STAR-48B motor before being mated with the IUS and spacecraft in July.

For logistical reasons the Shuttle to be used for the Ulysses launch (STS-41) has been changed from Atlantis to Discovery. The launch with this Orbiter immediately preceding Ulysses is the Hubble Space Telescope. Following the Orbiter's return to Earth, it will be modified to enable it to produce the nitrogen gas purge for the Ulysses experiments and the liquid cooling for the radioisotope thermoelectric generator (RTG), which is the power source for the Ulysses mission.

A press conference was held in ESTEC in November 1989 to celebrate the thermal-vacuum testing of the spacecraft and this resulted in considerable coverage in the European press. Further conferences are planned jointly with NASA in the USA both during the launch preparation and after launch.

All of the Ulysses elements are now coming together with adequate contingency time and without any great problems. On 17 May the launch campaign starts and everything looks set for a successful launch on 5 October and the five-year mission.

STSP

Despite SOHO's later start, the Agency is maintaining the so-called 'commonality' between the Cluster and SOHO projects during Phases B1 and B2, in order to maximise the exploitation of common equipment procurement. This approach will ensure that the geographical distribution targets for STSP as a whole are met, at the same time minimising the development effort required for both projects.

SOHO

The ESA/NASA agreements on SOHO were formally completed in November 1989, with the signing of the *se sera séparé de l'IUS. L'UMCS est maintenant installé au centre de contrôle du JPL où les essais de compatibilité avec les systèmes du JPL et le réseau pour l'espace lointain (DSN) de la NASA avancent de façon satisfaisante.*

La situation est également bonne en ce qui concerne l'IUS. Celui-ci se trouve déjà au KSC où sont exécutés quelques travaux préliminaires avant une brève période de stockage pour raisons logistiques. Le PAM-S se trouve lui aussi au KSC où il est assemblé à son moteur STAR-48B avant de l'être à l'IUS et au véhicule spatial en juillet.

Pour des raisons logistiques, ce sera Discovery et non plus Atlantis qui assurera le lancement d'Ulysse (STS-41). Ce même orbiteur aura alors lancé sur le Télescope spatial Hubble (prévu en avril). A son retour sur Terre, des modifications lui seront apportées pour lui permettre d'assurer la chasse de gaz à l'azote dont les expériences d'Ulysse auront besoin ainsi que le refroidissement par circulation de liquide du générateur radio-isotopique à thermocouple (RTG) chargé de l'alimentation en énergie de la mission Ulysse.

La conférence de presse tenue à l'ESTEC en novembre 1989 à l'occasion de la conclusion des essais thermiques sous vide du véhicule spatial a eu de larges échos dans la presse européenne. D'autres sont prévues avec la NASA, aux Etats-Unis, pendant la préparation du lancement et après celui-ci.

Toutes les composantes d'Ulysse se mettent en place avec les marges de sécurité voulues et sans aucun problème important. La campagne de lancement démarre le 17 mai et tout semble organisé pour un lancement réussi le 5 octobre et la mission de cinq ans qui doit lui faire suite.

STSP

Bien que SOHO démarre plus tard, l'Agence maintient une communité maximale entre les projets Cluster et Soho durant les phases B1 et B2 en vue d'exploiter au mieux les approvisionnements d'équipements communs. Les objectifs de répartition géographique d'ensemble du STSP pourront ainsi être respectés en même temps que l'effort de développement demandé par les deux projets sera limité à un minimum.

SOHO

Les accords entre l'ESA et la NASA concernant SOHO ont été officiellement scellés en novembre 1989 avec la signature du Mémorandum d'Accord et la confirmation de la charge utile.

La réunion de lancement de la phase B a ensuite eu lieu avec le maître d'oeuvre Matra les 28, 29 et 30 novembre 1989 à l'ESTEC. Les problèmes relevés lors de l'évaluation de la proposition ont été réglés et le contrat signé. La mise au point de divers sous-systèmes (AOCS, énergie, EGSE, propulsion) est déjà en route.

La phase B a été scindée en trois sous-phases en vue de la mise en oeuvre d'une politique d'approvisionnement d'ensemble rationnelle pour le STSP, les sous-phases B1 et B2 de Soho se déroulant parallèlement à celle de Cluster.

L'Exécutif évalue actuellement l'incidence de retards affectant la livraison de certaines expériences. Pour tout réaménagement du calendrier, il sera également tenu compte de la décision prise par l'ESA d'exécuter la totalité des activités d'intégration et d'essai en Europe.

La définition des interfaces des expériences a considérablement avancé et tous les documents s'y rapportant ont été mis à jour préalablement à la mise en route de la phase B de façon que la définition et la conception du système puissent démarrer sur des bases claires. Certains paramètres-clés de l'interface avec le lanceur et des données d'analyse de mission ont été arrêtés en accord avec la NASA. Les avantages qui en résultent sur le plan de la masse ont permis de dégager des ressources additionnelles pour les expérimentateurs et de simplifier la base de référence des opérations en vol.

Les prochaines étapes à franchir pour le projet SOHO seront la revue des impératifs au niveau système et la prochaine réunion du groupe de travail scientifique, toutes deux prévues pour mai.

Cluster

Depuis la réunion de lancement des travaux, les activités du maître d'oeuvre ont été axées sur la définition de la base de référence du système. Tous les plans et spécifications de ce niveau ont été achevés, ainsi que les spécifications du niveau sous-système.

La revue des impératifs système du véhicule spatial des 29 et 30 mars permettra de remettre aux industriels pour tous les sous-systèmes les dossiers de demande de prix et d'appel d'offres lancés pour le début de la phase 2 qui doit commencer le 1er mai.

La définition préliminaire des sous-systèmes se poursuit dans l'industrie avec l'attribution de contrats additionnels à Sener, Laben et ORS pour une assistance technique concernant respectivement les mâts, la gestion des données et les équipements mécaniques de soutien au sol (MGSE). A l'heure actuelle, l'ESA et Dornier travaillent en liaison avec Matra et l'équipe du projet SOHO de l'ESA à mettre sur pied une équipe industrielle répondant aux impératifs de répartition géographique.

L'ESA et le maître d'oevvre sont convenus d'inclure un modèle de structure dans le programme système. Il sera ainsi possible de faire progresser en parallèle les essais de qualification mécaniques sur le modèle de structure et les essais électriques sur le modèle d'identification, et de rattraper en grande partie les deux mois de retard causés par le démarrage tardif de SOHO tout en réduisant les risques de développement. Le calendrier de lancement est maintenu.

Les travaux relatifs à la charge utile avancent conformément aux plans avec seulement quelques problèmes mineurs à l'assemblage des matériels du modèle de développement. Un atelier scientifique commun Cluster/Regatta a été organisé à l'université technique de Graz en Autriche pour débattre des aspects scientifiques de la coopération entre les deux projets. Le véhicule spatial Regatta construit par l'Academie des sciences soviétique sera lancé peu après Cluster et placé sur une orbite similaire, ce qui permettra les corrélations entre les données des deux missions.

La prochaine réunion du groupe de travail scientifique est prévue pour fin

Memorandum of Understanding and the confirmation of the payload.

Following this, the Phase-B kick-off meeting with the prime contractor, Matra, took place at ESTEC on 28 – 30 November 1989. The problems identified during the proposal-evaluation phase were resolved and the contract has been signed. Various subsystems (AOCS, power, EGSE, propulsion) are already under development.

Phase-B has been split into three subphases to allow the implementation of a consistent STSP industrial procurement policy, with subphases Bl and B2 running in parallel with those of Cluster. The implications of delays in the delivery of some experiments are being assessed. Any rescheduling will also take into account ESA's decision to perform all integration and testing activities in Europe.

The experiment interface definition has has progressed considerably and all Experiment Interface Documents were updated prior to the start of Phase-B, in order to provide a clear basis for the system definition and design. Some key launcher interface parameters and mission analysis data have been agreed with NASA. The resulting benefits, in terms of mass, have allowed the release of additional resources to the experimenters and simplification of the in-flight operational baseline.

The next milestones for SOHO are the System Requirements Review and the next Science Working Team meeting, both of which take place in May.

Cluster
The major Prime Contractor activities since the kick-off meeting have centred on the definition of the system baseline. All system-level plans and specifications have been completed, together with the subsystem specifications.

The spacecraft system requirements review will take place on 29/30 March, releasing the RFQ/ITT packages to all sub-system contractors for the beginning of Phase B2, due to commence on 1 May.

Preliminary sub-system definition is continuing in Industry with additional contracts awarded to Sener, Laben and ORS for technical assistance on the booms, data-handling and MGSE, respectively. Currently ESA and Dornier are working in conjunction with Matra and the ESA SOHO project to achieve an industrial team which satisfies the requirements of geographical distribution.

ESA and the Prime Contractor have agreed to include a structural model in the system programme. This will enable mechanical qualification testing on the structural model and electrical testing on the engineering model to proceed in parallel, thus largely recovering the two-month delay incurred by the late start of SOHO and, at the same time, reducing development risk. The launch schedule is maintained.

The payload is progressing on schedule with only minor problems occurring as development model hardware is assembled. A joint Cluster/Regatta science workshop was held in Graz in Austria (hosted by the Technical University of Graz) to discuss the scientific aspects of cooperation between the two projects. The Regatta spacecraft, to be built by the Soviet Academy of Sciences, will be launched shortly after Cluster and placed in a similar orbit. This will enable Regatta data to be correlated with that of Cluster.

The next Science Working Team meeting is scheduled for late April and payload intermediate design reviews are planned for late summer, leading up to the overall system design review at the end of Phase-B.

ISO

The four Principal Investigator consortia are building their engineering-qualification models which are to be delivered toward the middle of this year for combined compatibility testing in a liquid-helium-cooled cryostat. Work is progressing well and action is being taken to recover predicted delays in the flight-model deliveries. All Principal Investigator groups have now confirmed that they will also deliver spare flight units to the Agency.

The structural-thermal model of the service module is fully integrated and will be delivered to the Prime Contractor in March for mechanical testing. The service-module structure has already been successfully static-load tested. The payload module (liquid-helium cryostat) has been integrated and evacuated. Technical difficulties in filling the cryostat with liquid helium are currently being resolved. An extensive series of cryogenic and thermal-vacuum tests of the payload module will continue on into the summer. All the qualification units of the satellite electrical subsystems are under manufacture.

Definition of the observatory ground segment is going well but requires increased manpower to cope with the high workload.

DRS

The Data-Relay System and Satellite and ground-segment Phase-B1 contracts are continuing and the second series of review meetings will be held in March. The DRS Development Programme Declaration was finalised at the Joint Communications Board (JCB) in January and is open for subscription until 21 March.

ERS

ERS-1

The integrated engineering-model payload/flight-model platform satellite has successfully completed radio-frequency-compatibility testing in the anechoic chamber at Intespace, Toulouse. The satellite was operated in all functional modes and no interference between instruments and house-keeping functions was apparent. Furthermore, margins were established for all critical receiver chains. The satellite has been de-integrated and and the platform made ready for integration with the flight-model payload.

The flight-model payload has been fully integrated and tested and was shipped to Matra at the end of February, for integration with the flight-model platform.

The Synthetic Aperture Radar (SAR) processor, part of the Active Microwave Instrument (AMI), has been successfully tested with the flight-model payload. Work now continues to finalise this unit for definitive installation in the satellite in June.

avril et les revues intermédiaires de conception de la charge utile pour la fin de l'été, conduisant à la revue de conception du système d'ensemble à la fin de la phase B.

ISO

Les quatre consortiums des chercheurs principaux élaborent actuellement les modèles d'identification et de qualification qu'ils devront livrer au milieu de l'année pour des essais de compatibilité combinés dans un cryostat refroidi à l'hélium liquide. Les travaux avancent à bon rythme et des mesures sont prises pour rattraper les retards prévus dans la livraison des modèles de vol. Les groupes des chercheurs principaux ont maintenant tous confirmé qu'ils livreront également des rechanges de vol à l'Agence.

Le modèle structure/thermique du module de servitude est entièrement intégré et sera livré en mars au maître d'oeuvre pour les essais mécaniques. La structure du module de servitude a déjà subi avec succès les essais de charge statique. Le module de charge utile (c'est-à-dire le cryostat à hélium liquide) a été intégré et mis sous vide. Les problèmes techniques posés par le remplissage du cryostat en hélium liquide sont en voie de résolution. Une importante série d'essais cryogéniques et thermiques sous vide du module de charge utile se poursuivra jusque durant l'été. Toutes les unités de qualification des sous-systèmes électriques du satellite sont en cours de fabrication.

La définition du secteur sol de l'observatoire est en bonne voie bien qu'un surcroît de personnel soit nécessaire pour faire face à la charge de travail importante.

DRS

L'exécution des contrats de phase B1 portant sur le satellite et le secteur sol du système de relais de données se poursuit et la deuxième série de revues aura lieu en mars. Le texte de la Déclaration relative au Programme de développement du DRS a été arrêté lors de la réunion de janvier du Conseil directeur commun des programmes de satellites de communications (JCB); elle est ouverte à la souscription jusqu'au 21 mars.

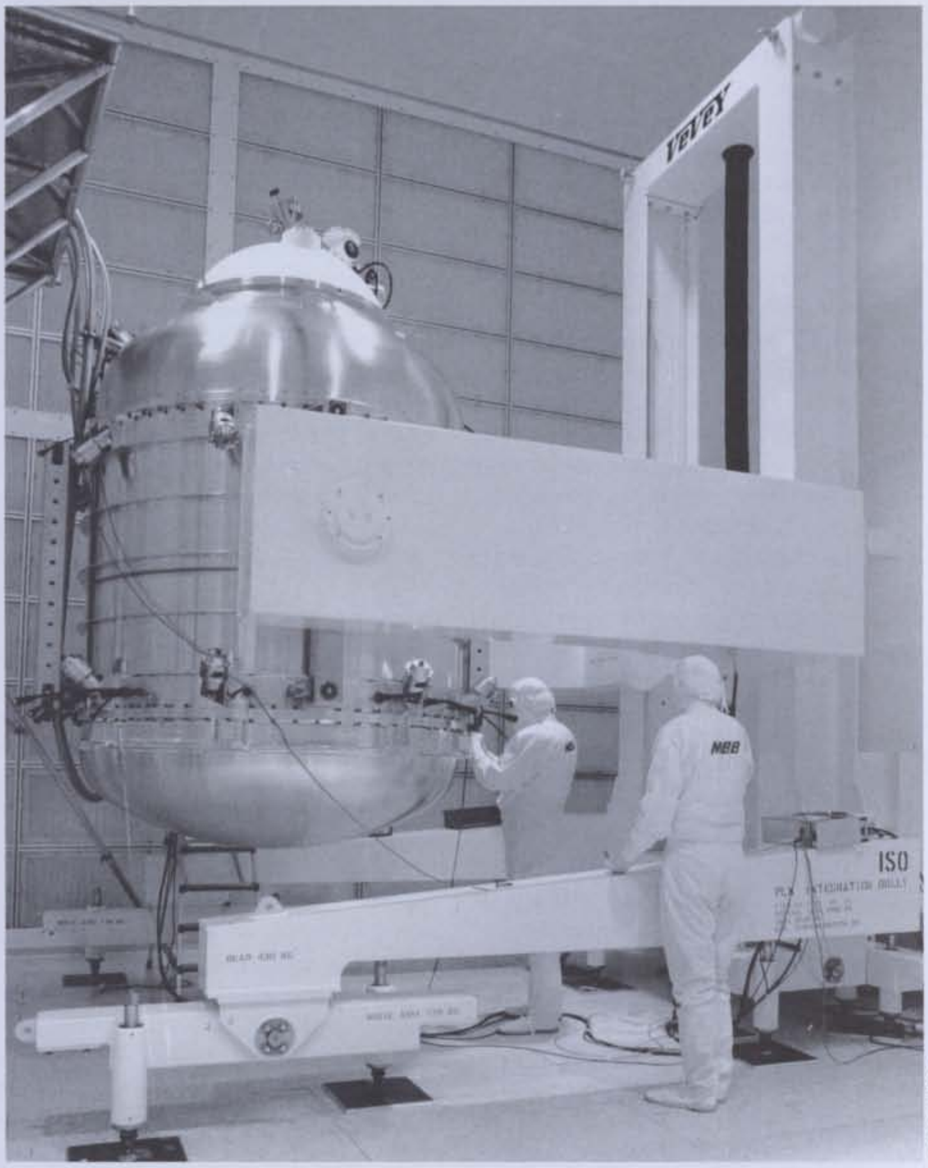


photo: MBB

Integrated ISO payload module (liquid-helium cryostat)

Le module de charge utile ISO intégré (cryostat refroidi à l'hélium liquide)

ERS

ERS-1

Le modèle d'identification de la charge utile a été intégré au modèle de vol de la plate-forme du satellite et a subi avec succès les essais de compatibilité radioélectrique dans la chambre anéchoïque d'Intespace à Toulouse. Tous les modes de fonctionnement du satellite ont été essayés et on n'a décelé aucune interférence entre le fonctionnement des instruments et des servitudes. On a en outre constaté que l'on disposait de marges pour toutes les chaînes de récepteurs critiques. Le satellite a été démonté et la plate-forme préparée en vue de son intégration au modèle de vol de la charge utile.

Après intégration et essais complets, celui-ci a été expédié à Matra fin février pour intégration au modèle de vol de la plate-forme.

Les essais avec le modèle de vol de la charge utile du processeur du radar à synthèse d'ouverture (SAR), qui fait partie du détecteur actif à hyperfréquences (AMI), ont été concluants. Les derniers travaux se poursuivent actuellement sur cette unité

Ground-segment activities continue, with the preparation and finalisation of the flight-operations procedures and the data-processing chains.

ERS-2

Following the adoption of the Enabling Resolution by the ESA Council, potential participants agreed on a programme declaration which is open for subscription by Member States until 21 March. The programme is due to start in April.

Preparatory work to establish the feasibility of the new Global Ozone Monitoring Experiment (GOME) is underway.

Meteosat

Operational Programme

Meteosat-4 (formerly MOP-1) had been used as primary spacecraft since June 1989. In the course of November, a condition developed on-board that caused noise in the image. As a precautionary measure, Meteosat-3 (P2) was brought back from its position over the Western Atlantic and in January operation was switched over to it, so that in-orbit tests could be conducted on Meteosat-4 without interrupting the operational service to meteorologists. (For latest information see page 96).

MOP-2 completed its test programme in preparation for a launch this Spring. It has now been placed in storage pending the decision on a new launch date. The prime contractor's team has started integration of MOP-3.

Pre-operational Programme

With Meteosat-3 (P2) back at 0°, the LASSO experiment has again been made available to the experimenters.

Earthnet

Acquisition, archiving, processing and distribution of Landsat, MOS-1, Spot and Tiros data have continued at the Fucino, Kiruna, Maspalomas and Tromsø stations.

Concerning new missions to be handled by the network, NOAA/Eosat have released the spacecraft-to-ground-station interface document for the Landsat-6 mission; the MOS-1b and Spot-2 satellites have been launched successfully.

The ESA-Spot Image agreement for access to Spot data by the Maspalomas station has been finalised.

A joint ESA-EEC initiative for medium-to-long-term global tropical-forest monitoring is being prepared, based on the exploitation of ERS-1 SAR data and AVHRR data, together with high-resolution visible and infrared data (Landsat and Spot).

The OCEAN project (processing and archiving of Nimbus-7 CZCS European data sets) is proceeding on schedule.

ERS-1

The ERS-1 SAR and low-bit-rate fast-delivery processing chains have been successfully installed in Frascati, together with the SAR verification-mode-processor software. The chains for the Gatineau (LBR), Maspalomas (LBR) and Fucino (SAR and LBR) ground stations have been manufactured and the units shipped to the sites for final installation. The antenna subsystems at these stations are currently being upgraded. Development of a subsystem that will transcribe the raw LBR data onto optical disk is underway.

The first meeting of the ERS-1 Ground Station Operators' Working Group was held in Frascati and was very successful.

The detailed design review of the French Processing and Archiving Facility (PAF) was held in November 1989. Work on both the algorithm development in Toulouse and the Operational Centre in Brest is progressing well.

The critical design review of the German PAF was held in December 1989. The SAR processor prototype has demonstrated the validity of the proposed algorithms. The UK PAF design review was held in November 1989.

Procurement proposals for the operation (1991 onwards) of the Fucino, Gatineau, Kiruna, Maspalomas and Tromsø stations and of the four ERS-1 PAFs have been prepared for submission to the ESA Industrial Policy Committee (IPC).

EOPP

Aristoteles

Following the successful completion of the system-definition review, the Aristoteles Additional Study is progressing well and the final presentation is will take place at ESTEC on 29 March.

In order to comply with all the design constraints, the overall configuration of the satellite has undergone a noticeable change in the layout of the hydrazine tanks, now reduced from eight to five. The design of the onboard data-handling and tracking telecommunication subsystems has been simplified to cope with a dedicated ground station at Kiruna with a 5 m dish antenna.

Satisfactory progress has been made on supporting studies such as the 'Geophysical interpretation of high-resolution gravity fields', special data-reduction studies, etc.

The Aristoteles Programme proposal is being finalised and will be issued to Delegations in the coming weeks.

Meteosat Second Generation (MSG)

Parallel system studies are underway on two different MSG configurations. The final presentation on the system studies of MSG as a spin-stabilised satellite took place on 31 January. The studies showed that the requirements of an imaging mission with much better performance than the current MOP series, can readily be met by a satellite in the half Ariane-4 class.

The mid-term review of the system study on MSG as a three-axis-stabilised satellite was completed in December 1989. The small optical package study was completed in January. The kick-off meeting of the high-spectral-resolution sounder study took place in November 1989.

Plans are being made jointly by the ESA Executive and the Eumetsat Secretariat for the start of Phase-A in 1991.

Polar-Orbit Missions

The main activities have been:

- Delegate-level meetings on the first Polar-Orbit Earth-Observation Mission (POEM-1)
- organisation of the first reviews on the

en vue de son installation définitive sur le satellite en juin.

En ce qui concerne le secteur sol, les activités se poursuivent avec la préparation et la mise au point des procédures d'exploitation en vol et des chaînes de traitement des données.

ERS-2

A la suite de l'adoption par le Conseil de l'ESA de la Résolution habilitante, les participants potentiels se sont mis d'accord sur une Déclaration de programme à laquelle les Etats membres pourront souscrire jusqu'au 21 mars. Le programme doit commencer en avril.

Des travaux préparatoires sont en cours afin de démontrer la faisabilité de la nouvelle expérience de surveillance de l'ozone à l'échelle du globe (GOME).

Météosat

Programme opérationnel

Météosat-4 (anciennement MOP-1) fonctionnait comme satellite principal depuis juin 1989. Au cours du mois de novembre, une anomalie de fonctionnement à bord a causé des bruits d'image. Par précaution, Météosat-3 (P2) a été ramené de la position qu'il occupait au-dessus de l'Atlantique ouest et a pris la relève en janvier, de manière à ce que l'on puisse conduire des essais en orbite sur Météosat-4 sans interrompre le service opérationnel (voir page 96).

MOP-2 est parvenu au terme du programme d'essais qui s'est déroulé en préparation de son lancement au printemps. Il est maintenant entreposé en attendant que soit fixée une nouvelle date de lancement. L'équipe du maître d'oeuvre a commencé l'intégration de MOP-3.

Programme préopérationnel

Météosat-3 (P2) étant de nouveau à 0°, l'expérience LASSO est de nouveau à la disposition des chercheurs.

Earthnet

L'acquisition, l'archivage, le traitement et la distribution des données de Landsat, de MOS-1, de Spot et de Tiros se sont poursuivis aux stations de Fucino, Kiruna, Maspalomas et Tromsø

En ce qui concerne les nouvelles missions à suivre par le réseau, la NOAA et Eosat ont publié le document d'interface satellite-station sol relatif à la mission Landsat-6 et les satellites MOS-1b et Spot-2 ont été lancés avec succès.

L'accord ESA/Spot Image relatif à l'accès aux données de Spot par la station de Maspalomas a été définitivement mis en forme.

On prépare actuellement un projet commun ESA/CEE pour la surveillance à moyen et long terme des forêts tropicales de l'ensemble du globe sur la base des données du SAR et de l'AVHRR d'ERS-1 ainsi que des données infrarouge et à haute résolution dans le visible de Spot et Landsat.

Le projet OCEAN (traitement et archivage des ensenbles de données CZCS de Nimbus-7 sur l'Europe) progresse conformément au calendrier.

ERS-1

Les chaînes de traitement des données LBR à livraison rapide et des données SAR d'ERS-1 ont été installées à Frascati ainsi que le logiciel du mode de vérification du SAR. Les chaînes des stations sol de Gatineau (LBR), Maspalomas (LBR) et Fucino (SAR et LBR) ont été fabriquées et les unités expédiées sur les sites pour y être définitivement installées. Les sous-systèmes des antennes de ces stations sont actuellement mis à hauteur. Un sous-système qui transcrira les données brutes LBR sur disque optique est en cours de réalisation.

La première réunion du groupe de travail des exploitants des stations sol d'ERS-1 qui s'est tenue à Frascati a donné de très bons résultats.

La revue de conception détaillée de l'installation de traitement et d'archivage (PAF) française a eu lieu en novembre 1989. Les travaux portant sur la mise au point de l'algorithme, à Toulouse, et sur le centre d'exploitation, à Brest, avancent de façon satisfaisante.

La revue de conception critique de la PAF allemande a eu lieu en décembre 1989. Le prototype du processeur SAR a permis d'obtenir confirmation de la validité des algorithmes proposés. La revue de conception de la PAF britannique s'est tenue en novembre 1989.

Des propositions d'approvisionnement pour l'exploitation (à partir de 1991) des stations de Fucino, Gatineau, Kiruna, Maspalomas et Tromsø ainsi que des quatre PAF d'ERS-1 ont été établies et seront soumises pour approbation au Comité de la politique industrielle de l'ESA (IPC).

EOPP

Aristoteles

La revue de définition du système a été menée à bien; l'étude supplémentaire sur la mission Aristoteles a bien avancé et la présentation finale de ses résultats aura lieu à l'ESTEC le 29 mars.

Afin de respecter l'ensemble des contraintes de conception, on a apporté à la configuration d'ensemble du satellite une modification notable portant sur l'agencement des réservoirs d'hydrazine dont le nombre est ramené de 8 à 5. Le concept des sous-systèmes de traitement des données à bord et de transmission des données de poursuite a été simplifié pour fonctionner avec une station sol spécialisée basée à Kiruna et équipée d'une antenne parabolique de 5 mètres de diamètre.

Les études de soutien — interprétation géophysique de champs de gravité à haute résolution, études spéciales de réduction des données, etc. — ont progressé de façon satisfaisante.

On procède actuellement à la mise en forme définitive de la proposition de programme Aristoteles qui sera envoyée aux délégations dans les semaines à venir.

Météosat de deuxième génération (MSG)

Des études au niveau système se déroulent en parallèle sur deux configurations différentes. La présentation finale des résultats des études d'une version à stabilisation par rotation du MSG a eu lieu le 31 janvier. Ces études ont montré que les besoins d'une mission d'imagerie dont les caractéristiques de fonctionnement

First Polar Mission (FPM) Phase-A study
- interface with the Columbus programme to review the Polar Platform specification
- interface with the Space Science Directorate on space-science instruments earmarked for the FPM
- interface with all Announcement of Opportunity (AO) instrument providers
- liaison with Eumetsat to harmonise FPM activities
- instrument consultancy group meetings.

The February EOSTAG meeting was devoted to a review of results of the past campaign activities and the definition of a future strategy.

TDP

Experiments

Gallium Arsenide Solar Array (GaAs)
The experiment (solar panel with experimental patch) was launched on-board UoSat-E in January. 30 hours into the flight the satellite stopped sending telemetry. Until then the data had indicated that this experiment was working nominally. Attempts to recover the small satellite are in progress.

Phase-2, the solar panel with 2×4 cm, cells with welded interconnectors is progressing on schedule.

The *Transputer and Single-Event Upset experiment* was also launched on-board UoSat-E and had not yet been switched on when contact with the satellite was lost.

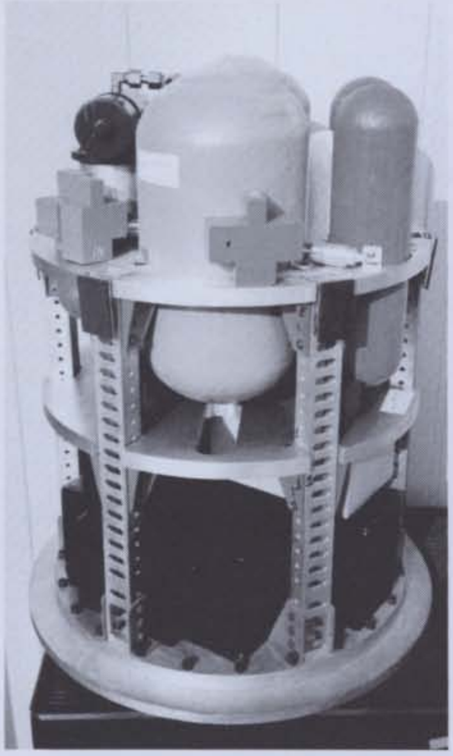
Solid-State Micro-Accelerometer
The flight unit is being prepared for shipment to the launch site.

Attitude Sensor Package
Due to carrier requirement changes the Critical Design Review is now foreseen for the Spring.

Collapsible Tube Mast
The bridging phase, preceding Phase C/D, will start in March.

Metal Deposition In-Orbit
The preliminary design review (PDR) is now foreseen for April/May.

Liquid Gauging Technology
The PDR was successfully completed last February. A parabolic flight is scheduled for the summer to finalise design parameters prior to the CDR.



Maquette de l'expérience de jaugeage des liquides (G-22)

Liquid-Gauging Technology experiment (G-22) mock-up

Inflatable Space-Rigidised Technology
A contract for the phases A/B of the inflatable boom experiment will be awarded in March.

Two-Phase Flow
The development of the experiment will start in April.

Common Support Subsystems
The Payload Control Unit will be delivered to the first user, the Attitude Sensor Package, in the Spring. The first unit of the Hitchhiker-G simulator has been delivered.

ESA/NASA Cooperative Experiments

Agreement on the In-Flight Contamination Experiment (IFCE) and Solar Array Module Plasma Interaction Experiment (SAMPIE) is still pending the CTM status.

Flight Opportunities

For the Hitchhiker-G experiments (Attitude Sensor Package and Collapsible Tube Mast) the launch is confirmed on STS-50, by end 1991. The Solid-State Micro-accelerometer (Get-Away Special G-21) has been assigned to the STS-40 flight in August 1990.

TDP Next Phase Preparation

A preliminary programme for the TDP next phase, was discussed with Industry at a workshop held at ESTEC in February.

Hermes

The major actions undertaken at the system and spaceplane reviews carried out in 1989 are nearing completion. The main result was a reassessment of the solutions proposed for key requirements of the spaceplane, with the aim of increasing the overall reliability and reducing unnecessary dependence on unproven technologies. In several cases, this reassessment led to the introduction of a simpler technical approach, without affecting the Hermes mission objectives or the overall configuration selected in Autumn 1988.

The most important decision was the selection of 'Mach 3' ejectable seats for crew escape, instead of an ejectable cabin. This decision was taken after detailed consideration of the cabin definition results; the advantage of the latter's somewhat wider application was overridden by the penalty on overall spaceplane design and reliability and the complexity of its qualification programme.

Two other important changes were the selection of aluminium, instead of high-temperature carbon composite, as the airframe material, and the simplification of the injection of Hermes into its transfer orbit, no longer requiring a propulsion module.

With several improvements in the internal accommodation, a reduction in the complexity and cost of the MRH module, and the confirmation of major aerodynamic and thermal protection options, it is expected that the consolidated baseline can be confirmed in April. This baseline will be the basis of the industrial offer for Phase-2, the preparation of which has already started. This will be the most important objective of the year.

Similar preparation work has been carried out in other areas. The *seraient de beaucoup supérieures à celles de la série MOP actuelle pouvaient aisément être satisfaits par un satellite de la classe demi-Ariane-4.*

La revue à mi-parcours de l'étude d'un satellite MSG à stabilisation triaxiale a été menée à bien en décembre 1989. L'étude du petit ensemble d'instruments optiques a pris fin en janvier. La réunion de mise en route de l'étude du sondeur à haute résolution spectrale s'est tenue en novembre 1989.

L'Exécutif de l'ESA et le secrétariat d'Eumetsat préparent conjointement le démarrage de la phase A en 1991.

Missions sur orbite polaire

Les principales activités ont été les suivantes:

- *réunions au niveau des délégués sur la première mission d'observation de la Terre sur orbite polaire (POEM-1)*
- *organisation des premières revues de l'étude de phase A sur la première mission polaire (FPM)*
- *interface avec le programme Columbus pour l'examen des spécifications de la plate-forme polaire*
- *interface avec la Direction Sciences spatiales au sujet des instruments de science spatiale devant être embarqués sur la FPM*
- *interface avec tous les fournisseurs d'instruments candidats dans le cadre de l'avis d'offres de participation (AO)*
- *liaison avec Eumetsat en vue de l'harmonisation des activités FPM*
- *réunions des groupes de consultants qui étudient les instruments.*

La réunion de février de l'EOSTAG a été consacrée à l'examen des résultats des activités des campagnes passées et à la définition d'une stratégie future.

TDP

Expériences

Générateur solaire à l'arséniure de gallium (GaAs)
L'expérience générateur solaire avec une série d'éléments expérimentaux a été lancée à bord d'UoSat-E en janvier. Au bout de 30 heures de vol, le satellite a cessé l'envoi de télémesures. Jusque là, les données indiquaient que cette expérience fonctionnait de façon nominale. On tente actuellement de rétablir le contact avec le petit satellite.

La phase 2 de cette expérience qui porte sur un panneau solaire équipé de piles de 2×4 cm à interconnecteurs soudés progresse conformément au calendrier.

L'expérience 'transordinateur et perturbations sous l'effet de particules élémentaires', *également lancée à bord d'UoSat-2, n'avait pas été mise sous tension lorsque l'on a perdu contact avec le satellite.*

Micro-accéléromètre à l'état solide
L'unité de vol est actuellement préparée pour expédition sur le site de lancement.

Ensemble de détecteurs d'orientation
Les impératifs relatifs au moyen porteur ayant été modifiés, il est maintenant prévu que la revue de conception critique ait lieu au printemps.

Mât à tube enroulable
La phase relais précédant la phase C/D commencera en mars.

Expérience de dépôt de métaux en orbite
La revue de conception préliminaire (PDR) est maintenant prévue pour avril-mai.

Technologie de jaugeage des liquides
La PDR qui s'est déroulée en février dernier a été concluante. Un vol parabolique doit avoir lieu cet été pour arrêter les paramètres de conception avant la CDR.

Technologie de structures gonflables, rigidifiables dans l'espace
Un contrat portant sur les phases A/B de l'expérience de mât gonflable sera attribué en mars.

Ecoulement diphasique
La mise au point de l'expérience commencera en avril.

Sous-systèmes de soutien communs
L'unité de contrôle de charge utile sera livrée ce printemps au premier utilisateur, l'ensemble de détecteurs d'orientation. La première unité du simulateur Hitchhiker-G a été livrée.

Expérience en coopération ESA/NASA

En ce qui concerne les accords relatifs à l'expérience de contamination en vol (IFCE) et à l'expérience d'interactions entre le module de générateur solaire et le plasma (SAMPIE), on continue d'attendre le résultat de la phase relais du CTM.

Occasions de vol

Le lancement des expériences Hitchhiker-G (ensemble de détecteurs d'orientation et mât à tube enroulable) est confirmé pour 1991 sur le STS 50. L'expérience GAS de micro-accéléromètre à l'état solide (G21) a été affecté au vol STS-40 prévu pour août 1990.

Préparation de la phase suivante du TDP

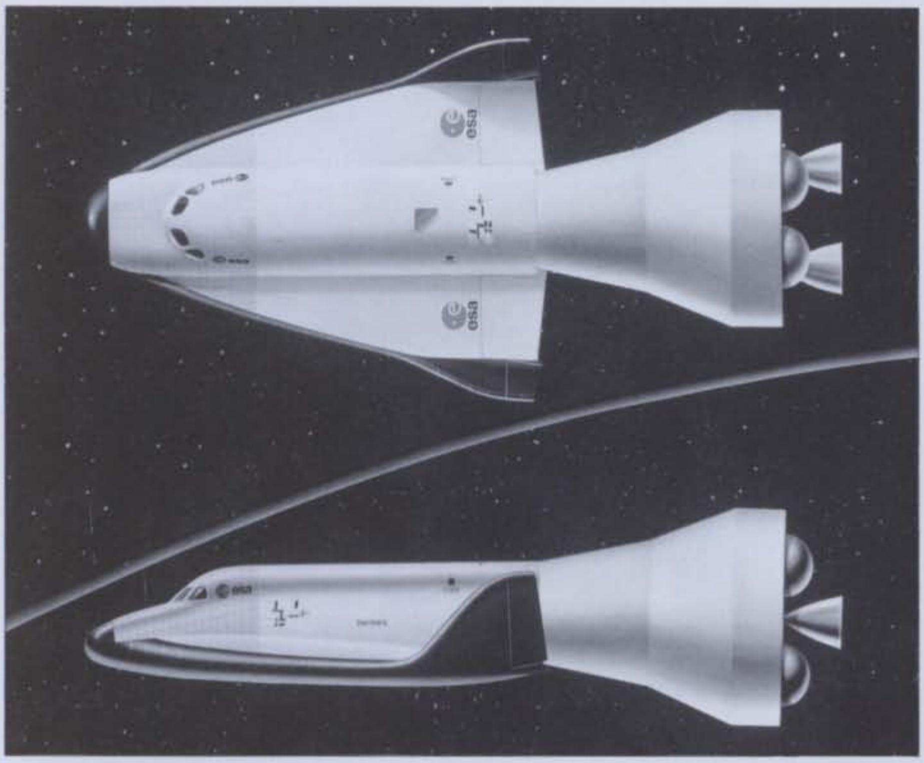
Pour la prochaine phase du TDP, un programme préliminaire a été étudié avec l'industrie lors d'un atelier qui s'est déroulé à l'ESTEC en février.

Hermès

Les principales actions engagées à l'issue des revues 'système' et 'avion spatial' de 1989 sont presque terminées. Elles ont eu pour résultat une réévaluation des solutions proposées en ce qui concerne les impératifs-clés de l'avion spatial avec l'objectif d'accroître sa fiabilité générale et de réduire au strict nécessaire l'usage de technologies n'ayant pas fait leurs preuves. Dans plusieurs cas, cette réévaluation a conduit à la mise en oeuvre de formules techniques plus simples sans que les objectifs de la mission Hermès ou la configuration globale choisie à l'automne 1988 en soient affectés.

La décision la plus importante a été le choix pour le sauvetage de l'équipage de sièges éjectables 'Mach 3' en lieu et place d'une cabine éjectable. Cette décision a été prise après examen détaillé des résultats de la définition de la cabine; les avantages du champ d'application légèrement plus vaste de cette dernière solution ont été jugés insuffisants pour contrebalancer les pénalités qu'elle impose sur la conception globale de l'avion spatial et sur sa fiabilité ainsi que la complexité du programme de qualification.

Deux autres changements importants sont à noter: la sélection de l'aluminium comme matériau de la cellule au lieu du composite carbone haute température et la simplification de l'injection d'Hermès sur son orbite de transfert qui n'exige plus un module de propulsion.



Vue conceptuelle de'Hermès

Artist's impression of Hermes

configuration reviews of the HERA and EVA development contracts were held successfully. Major progress was made on the definition of the ground segment, and the main contract for the flight control centre is about to start.

Finally, the definition of the operational phase, the Hermes utilisation programme and the related astronaut activities is progressing satisfactorily.

All these actions are in preparation for the decision on the transition to Phase 2 for both Hermes and Columbus, to be taken in June 1991.

Ariane

Ariane-5 Development Programme

P230 boosters
An important milestone in booster development was reached in December 1989 with the hot firing of the first demonstration flight engine. Loaded with 15 tonnes of grain, this demonstration model produced by SEP involved implementation of the principal technologies used in the P230 booster design. Particular mention should be made of the segmented propellant, heat shields, intersegment seals, the materials used in the nozzle throat and the flexible bearing. Hardware inspection following this test showed the components as a whole to be in good condition and confirmed the definition of the first, full-scale P230 booster, scheduled for testing in Guiana in August 1991.

Vulcain engine
Tests on the Vulcain engine subsystems, also run in December 1989, proved extremely encouraging. The liquid hydrogen turbopump emerged successfully from its first test with the turbine driven by hot gas from the flight-standard generator. This turbopump has now been integrated on the first Vulcain engine M_1.

The combustion chamber for the M_1 engine was accepted following a 15 s, 107 tonne thrust hot test.

Tests at the Ottobrunn teststand on the turbopump, fuelled by liquid oxygen, enabled the version for the M_1 engine to be acceptance-tested.

At the end of February, the first Vulcain engine was 80% integrated, meaning that the date of early April 1990 could be confirmed for mounting on the teststand.

Etant donné les améliorations apportées à l'installation interne, la réduction de la complexité et du coût du module MRH et la confirmation des principales options en matière d'aérodynamique et de protection thermique, la configuration de référence consolidée devrait pouvoir être confirmée en avril. Cette configuration de référence servira de base à la proposition industrielle de phase 2 dont la préparation a déjà commencé. Ce sera l'objectif le plus important de l'année 1990.

Des travaux de préparation similaires ont été exécutés dans d'autres domaines. Les revues de configuration des contrats de développement ERA et EVA se sont déroulées avec succès. Des progrès importants ont été faits dans la définition du secteur sol, et le contrat principal relatif au centre de contrôle en vol est sur le point de commencer.

Enfin, la définition de la phase opérationnelle, le programme d'utilisation d'Hermès et les activités correspondantes des astronautes progressent de façon satisfaisante.

Toutes ces mesures préparent la décision sur le passage à la phase 2 d'Hermès et de Columbus qui doit être prise en juin 1991.

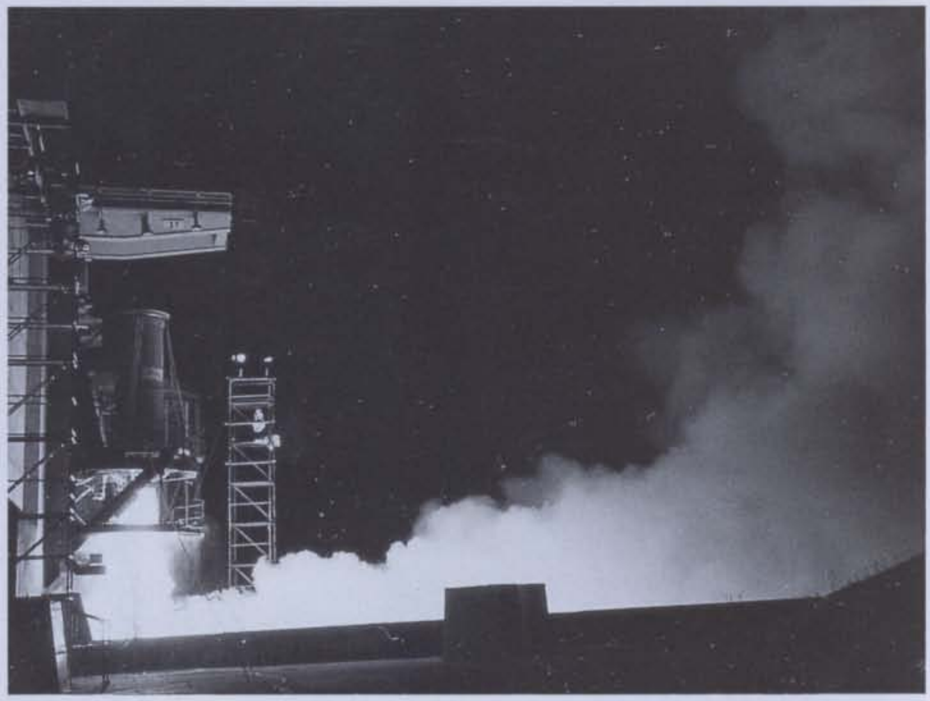
Ariane

Programme de développement Ariane-5

Propulseur P230

Une étape importante du développement des propulseurs a été franchie en décembre 1989 lors de l'essai à feu de 1er moteur technologique. Chargé de 15 tonnes de poudre, ce démonstrateur, produit par la SEP, mettait en oeuvre les principales technologiques qui sont retenues dans la conception des P230. Parmi celles-ci il faut signaler le propergol segmenté, les protections thermiques, les joints intersegments, les matériaux du col de la tuyère et une butée flexible.

L'expertise du matériel après cet essai qui montre la bonne tenue de l'ensemble des composants confirme la définition choisie pour la réalisation du 1er propulseur P230 à l'échelle 1, dont l'essai en Guyane est prévu en août 1991.



Successful firing test of the 15-tonne solid booster

Essai réussi du moteur expérimental chargé de 15 tonnes de poudre

Moteur Vulcain

En décembre 1989 également, les essais des sous-systèmes du moteur Vulcain ont été très encourageants. En effet la turbopumpe hydrogène liquide a subi avec succès le premier essai avec entraînement de la turbine par des gaz chauds issus du générateur de gaz de type vol. Cette turbopompe est maintenant intégrée sur le premier moteur Vulcain M_1.

La recette de la chambre de combustion, destinée au moteur M_1, a été prononcée après un essai à feu de 15 s à 107 tonnes de poussée.

Sur le banc d'Ottobrunn les essais de la turbopompe, alimentée en oxygène liquide, ont permis de recetter l'exemplaire destiné au moteur M_1.

A la fin de février l'intégration du 1er moteur Vulcain est effectuée à plus de 80% ce qui permet de confirmer la date de la mise au banc, début avril 1990.

Publications

The documents listed have been issued since the last publications announcement in the Bulletin. Requests for copies should be made in accordance with the Table and using the Order Form inside the back cover of this issue.

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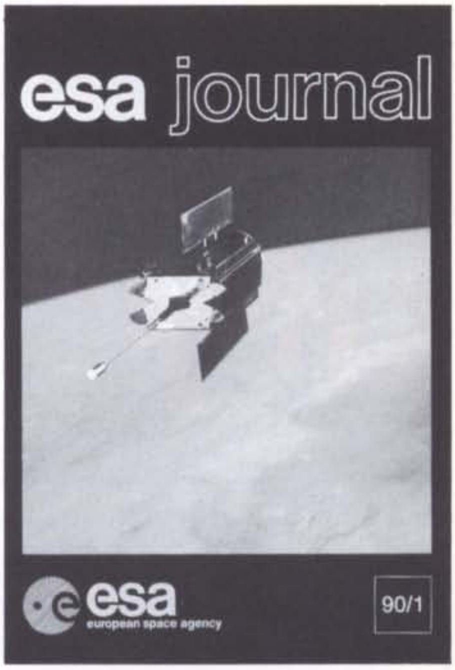

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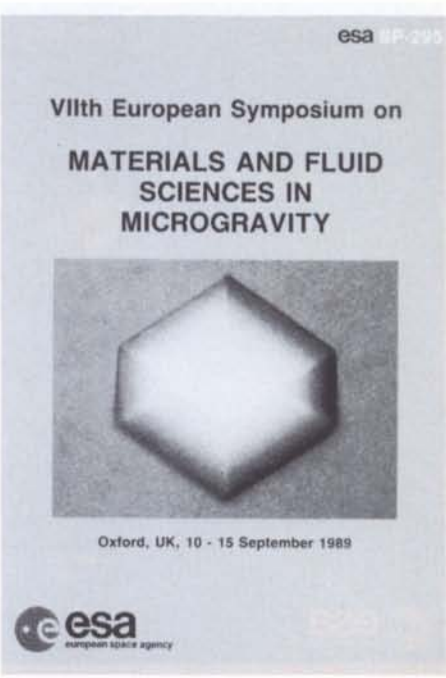

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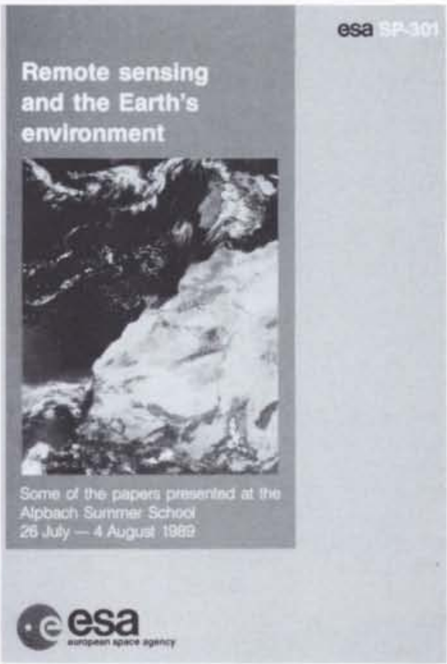

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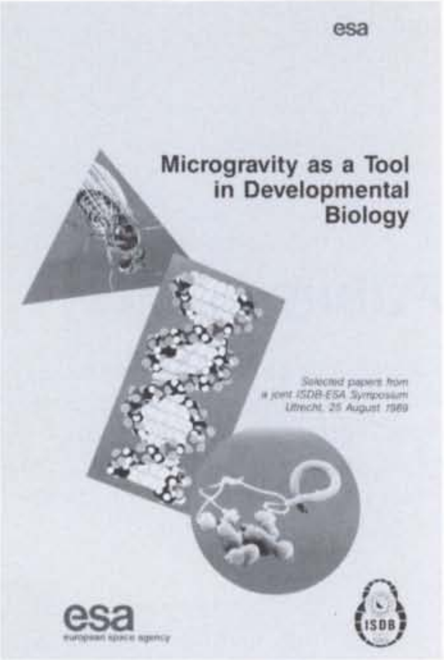

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