european space agency

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agence spatiale européenne

number 76

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european space agency

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agence spatiale européenne

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Cover: Hamburg (D) as seen by ERS-1's Synthetic Aperture Radar (SAR) instrument. This data set is a composite of three images acquired on 3 January (blue), 18 April (green) and 1 August 1993 (red)

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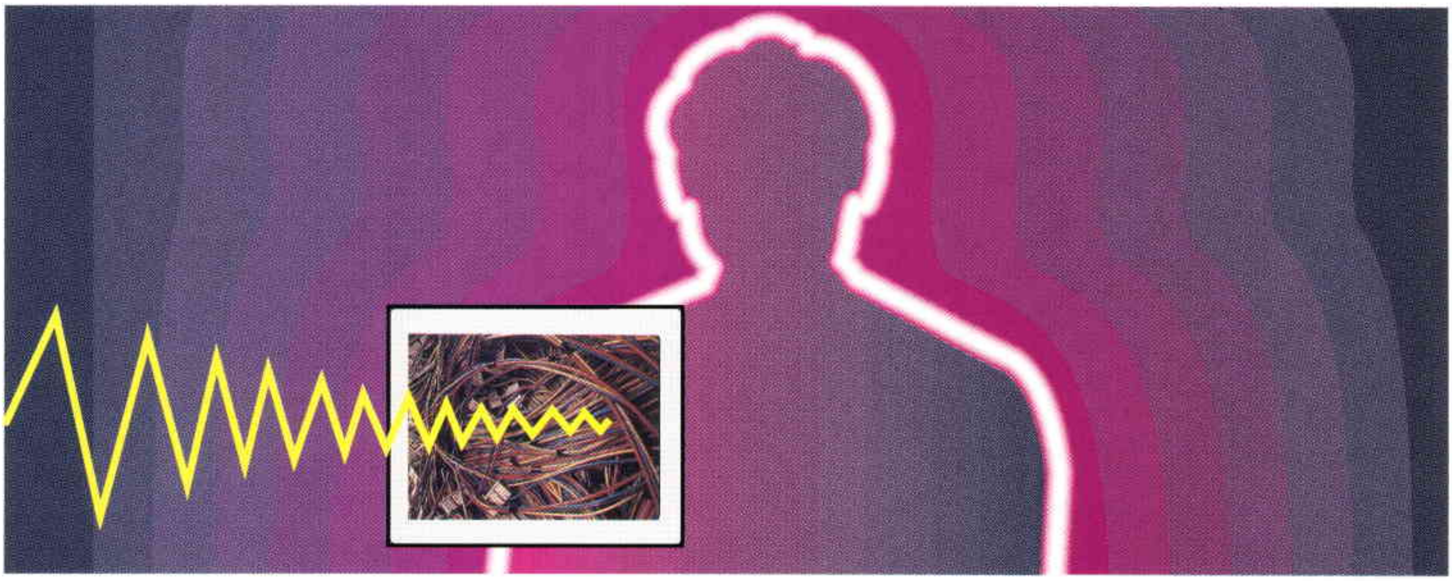

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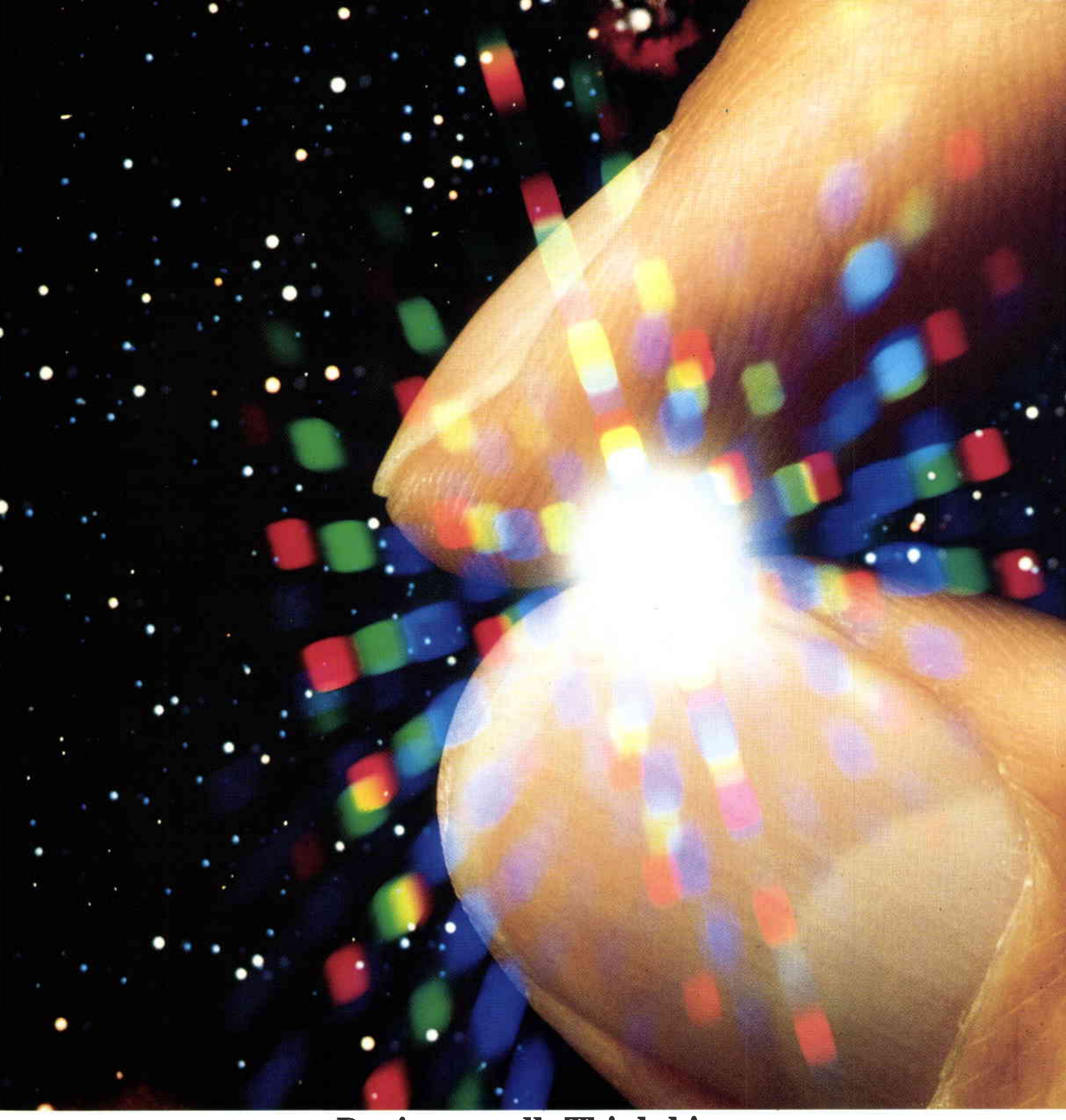

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PEMA 2B

Introduction

Following the launch of ESA's first remote-sensing satellite ERS-1 in 1991 and its continuing successful operations, the Agency is looking forward to the launch of its successor, ERS-2, which will ensure continuity in the provision of space-acquired remote-sensing data to the ever-growing community of users. At the same time, ESA is also preparing for a future Earth-observation mission responsive to user needs into the next century. It is based on use of the Polar Platform developed within the Columbus Programme, equipped with a set of key instruments for environmental monitoring from space.

This future mission, known as 'Envisat-1', responds to Europe's increasing awareness of the environmental problems that we face by catering to the future needs of the international community of users – both science- and applications-oriented – of remote-sensing data. Envisat will furnish reliable data on a global basis and over long periods of time, thereby contributing to a much better understanding of the complex phenomena governing the well-being of our precious but fragile environment.

The eight articles that follow are intended to provide both an insight into the historical background to the Envisat mission and its rationale, as well as a basic understanding of the roles of some of the complex instruments that this first Polar Platform mission will carry and which will be operated in space well into the next century.

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Envisat and the Polar Platform: The Concept and Its History

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Following the decisions taken at the ESA Council at Ministerial Level in Granada last November, use of the European Polar Platform as the basis for the Envisat Programme has been confirmed. A well-balanced set of instruments has now been selected to make up the payload complement for Envisat-1 and a nominal Industrial Consortium arrived at for its development. This article briefy traces the history of the Programme and outlines the current mission concept and the proposed industrial organisation for its implementation.

Introduction

The issue of how man interacts with the environment and, in more general terms, the ecological consequences of all human activities started to be a matter of increasing public interest in the late 1960s. In recent years, it has become one of the major topics of discussion in everyday life. The 'greenhouse effect', acid rain, the hole in the ozone layer and the systematic destruction of the tropical rain forests are all now the subjects of passionate debate.

This new awareness of the environmental and climatic changes that may be overtaking our entire planet has provided support for a growing scientific interest in the complex interactions that occur between the Earth's atmosphere, oceans, ice regions and land surfaces. This scientific interest has created, over the years, a well-established community of scientists active in these disciplines.

At the same time, the global perspective of the Earth's environment has fostered the development of a number of space-based remote-sensing techniques for earth observation. Starting with its ERS-1 Programme, ESA has played a key role in the development of these techniques for a wide range of applications. In 1988, all of these elements were drawn together in an ESA proposal to its Member States for an overall 'Strategy for Earth Observation'. A series of polar-orbiting and geostationary satellites was foreseen, to support several missions covering, in particular, the study of the Earth's environment and resources, the continuation and improvement of meteorological observations, and the study of the structure and dynamics of the Earth's crust and interior.

Based on the scenario defined in that ESA strategy for Earth-Observation Programmes, the first Polar Orbit Earth Observation Mission (POEM-1) was established as an optional Agency Programme, via a Resolution of the ESA Council Meeting at Ministerial Level in Munich in November 1991. The exact content of the POEM-1 Programme was subsequently elaborated in a further Resolution, adopted at the next ESA Council Meeting at Ministerial Level, in Granada in November 1992. On this occasion, the two constituent elements of the Programme were further defined as the Envisat-1 mission and the Metop-1 mission preparatory programme.

With its launch foreseen for late 1998, Envisat-1 will be the first earth-observation mission based on exploitation of the European Polar Platform. It is primarily a research-oriented mission and will carry essentially pre-operational instruments for monitoring and studying the Earth's environment, including climate changes. The later Metop-1 mission will be more oriented to routine operational observations and climate monitoring.

Major mission elements

The two major elements of the Envisat-1 mission are:
- the space segment, consisting of the Envisat-1 Payload Instruments on the Polar Platform (PPF), and
- the ground segment, composed of the Flight Operations Segment and the Payload Data Segment.

The space segment

The overall configuration of Envisat-1 (Fig. 1)

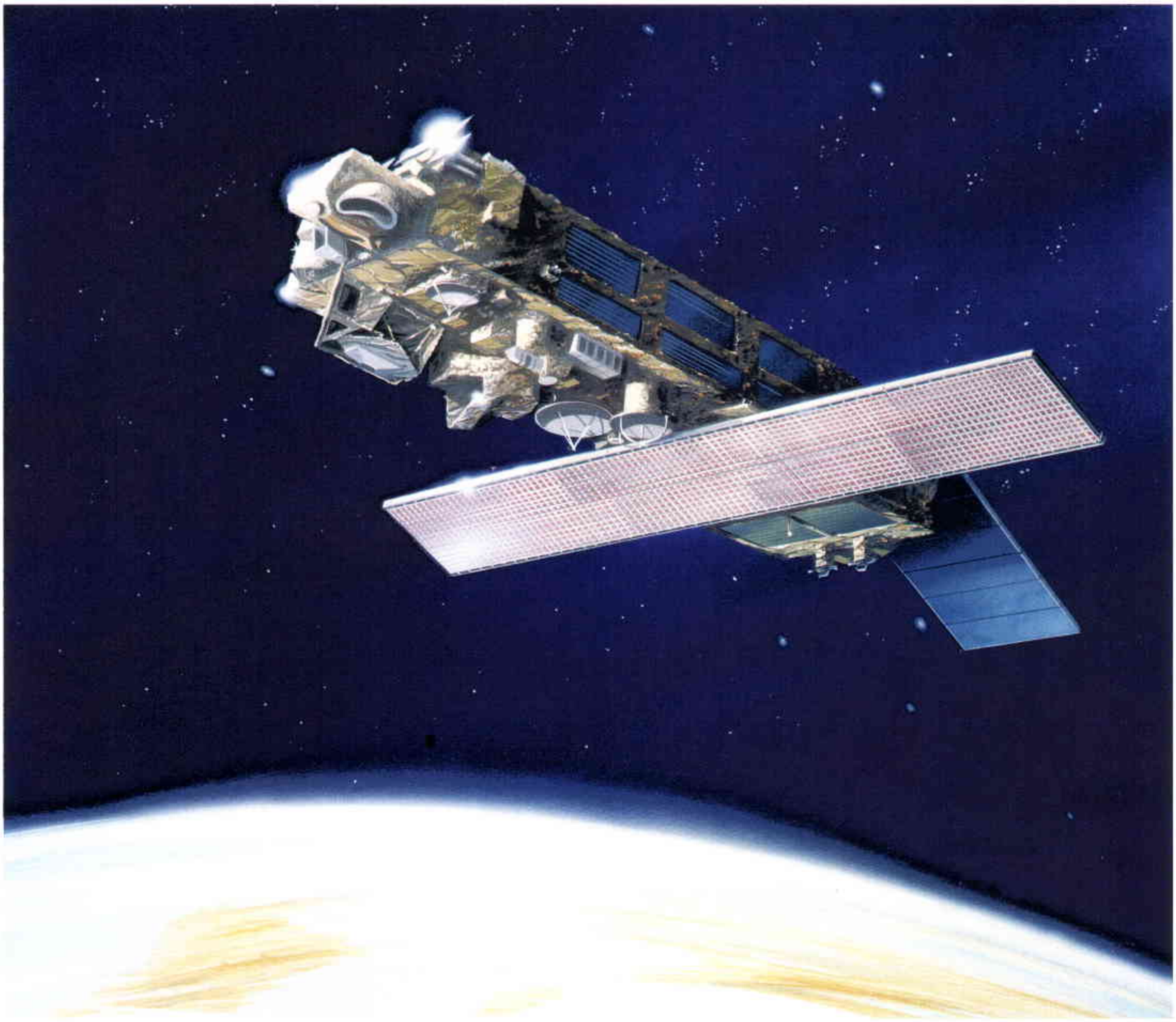


Figure 1. Artist's impression of Envisat-1

is driven by the instruments' observation and accommodation needs, the Polar Platform's general layout and the need to be compatible with the Ariane-5 fairing.

The configuration of the Payload Module has been the object of intense and careful optimisation in order to accommodate all the instruments physically and provide them with the requisite fields of view, whilst still respecting a number of inherent constraints in terms of necessary clearances, etc. In particular, a detailed trade-off was performed between a three-sections versus a four-section PPF Payload Module (PLM). It was concluded that, for the chosen Envisat-1 payload complement, a three-section PLM did not offer sufficient accommodation space or surface-mounting area. The final configuration of the four-section Payload Module and the locations of the various instruments are shown in Figure 2.

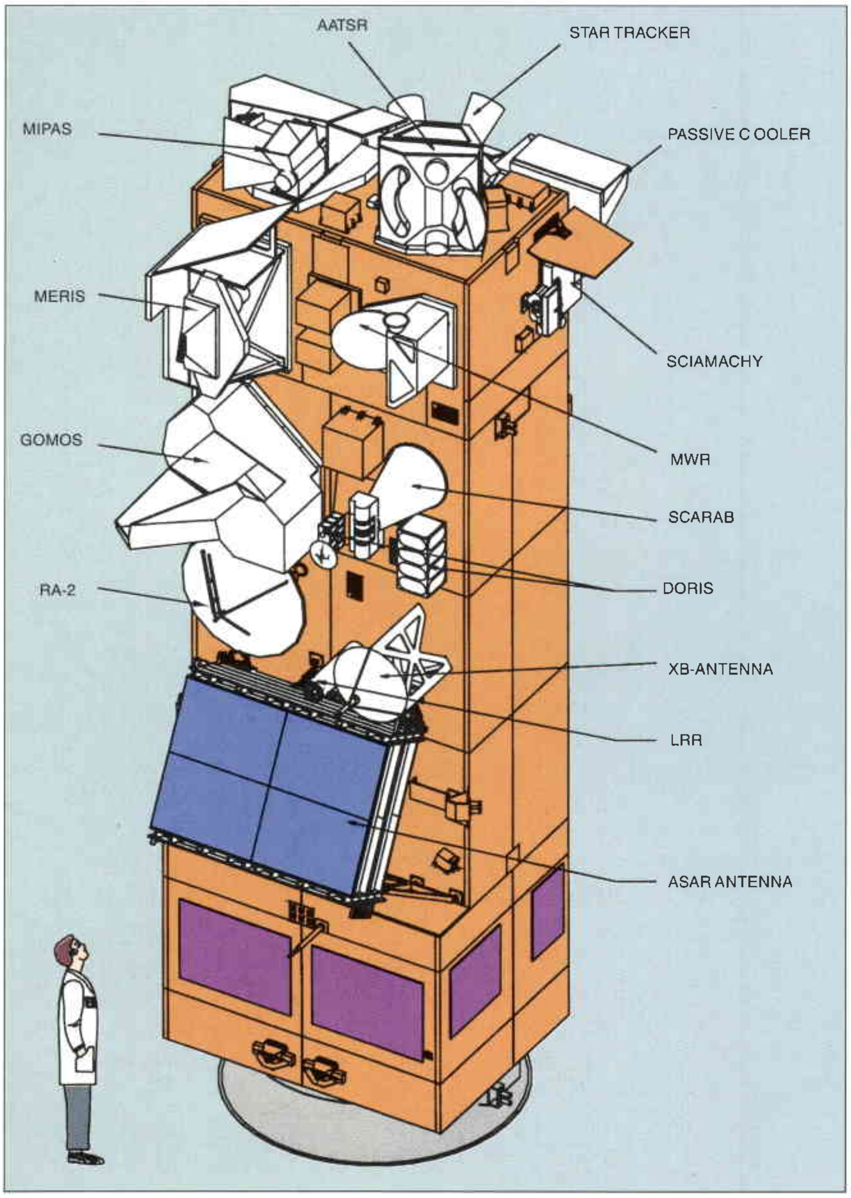
Most of the instruments are mounted on the outside of the PLM, while the electronics units for the ASAR, RA and GOMOS instruments have been accommodated, together with the PPF electronics, inside the Payload Equipment Bay (PEB). The instruments themselves are described in detail in the companion articles in this issue of Bulletin. It should perhaps be recalled here, however, that the selected payload complement consists of a group of ESA Developed Instruments (EDIs), funded under the Envisat-1 Programme, and a group of Announcement of Opportunity (AO) Instruments, funded nationally by the Participating States:

EDI instruments
- Medium-Resolution Imaging Spectrometer (MERIS)
- Michelson Interferometric Passive Atmospheric Sounder (MIPAS)

- Advanced Radar Altimeter (RA-2), including a Microwave Sounder
- Advanced Synthetic Aperture Radar (ASAR) capable of operating in both imaging and wave modes
- Global Ozone Monitoring by Occultation of Stars (GOMOS)
- Microwave Radiometer (MWR).

AO instruments
- Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY), provided by Germany and The Netherlands
- Advanced Along-Track Scanning Radiometer (AATSR), provided by the United Kingdom
- Scanner for Radiation Budget (SCARAB), provided by France
- Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS), provided by France.

Figure 2. The Envisat-1 payload



The main design and development Phase (Phase-C/D) for the ESA-developed instruments was started in July 1992. Detailed design activities were initiated first at the level of the mission and instrument prime contractors, whilst the complete make-up of the Envisat-1 Industrial Consortium was being finalised. As this has now essentially been decided, work can proceed in all areas.

The next important milestone is the satellite and mission-level Preliminary Design Review (PDR) in Spring 1994. Preparations for this are already well underway, including PDRs for the entire PPF and some of the instruments.

In its role of Mission Prime Contractor, Dornier GmbH (D) is leading the Consortium of more than 50 European and Canadian companies. The Instrument Prime Contractors for the EDI instruments are:
- Aerospatiale (F) for MERIS
- Alenia Spazio (I) for RA-2
- DASA (D) for MIPAS
- MMS-F (F) for GOMOS
- MMS-UK (UK) for ASAR/MWR.

An overall schedule for the Envisat-1 mission elements is shown in Figure 3.

The Polar Platform

The Polar Platform Programme was started in the framework of the Columbus Programme back in 1987. After several iterations of the Platform concept (serviceable or not) and its basic characteristics (payload mass and power capabilities), it was decided at the end of 1989 to start the development of a multi-mission Polar Platform offering a modular range of capabilities to the payload. (The multi-mission Polar Platform was extensively described in ESA Bulletin No. 71, in August 1992).

Following the decisions taken in November 1992 at the Granada Ministerial Conference to split the POEM-1 Mission (for which the PPF, at its upper range of capabilities, was particularly well-suited) into the Envisat-1 and Metop-1 series of missions, the Polar Platform Programme has been reoriented to support these programmes, concentrating initially on the Envisat-1 mission. To this end, the design modularity existing in the multi-mission PPF has been used to tailor it to the specific Envisat-1 mission needs.

The Polar Platform is comprised of two major modules (Fig. 4):
- The Service Module, the design of which is largely derived from Spot-4, provides

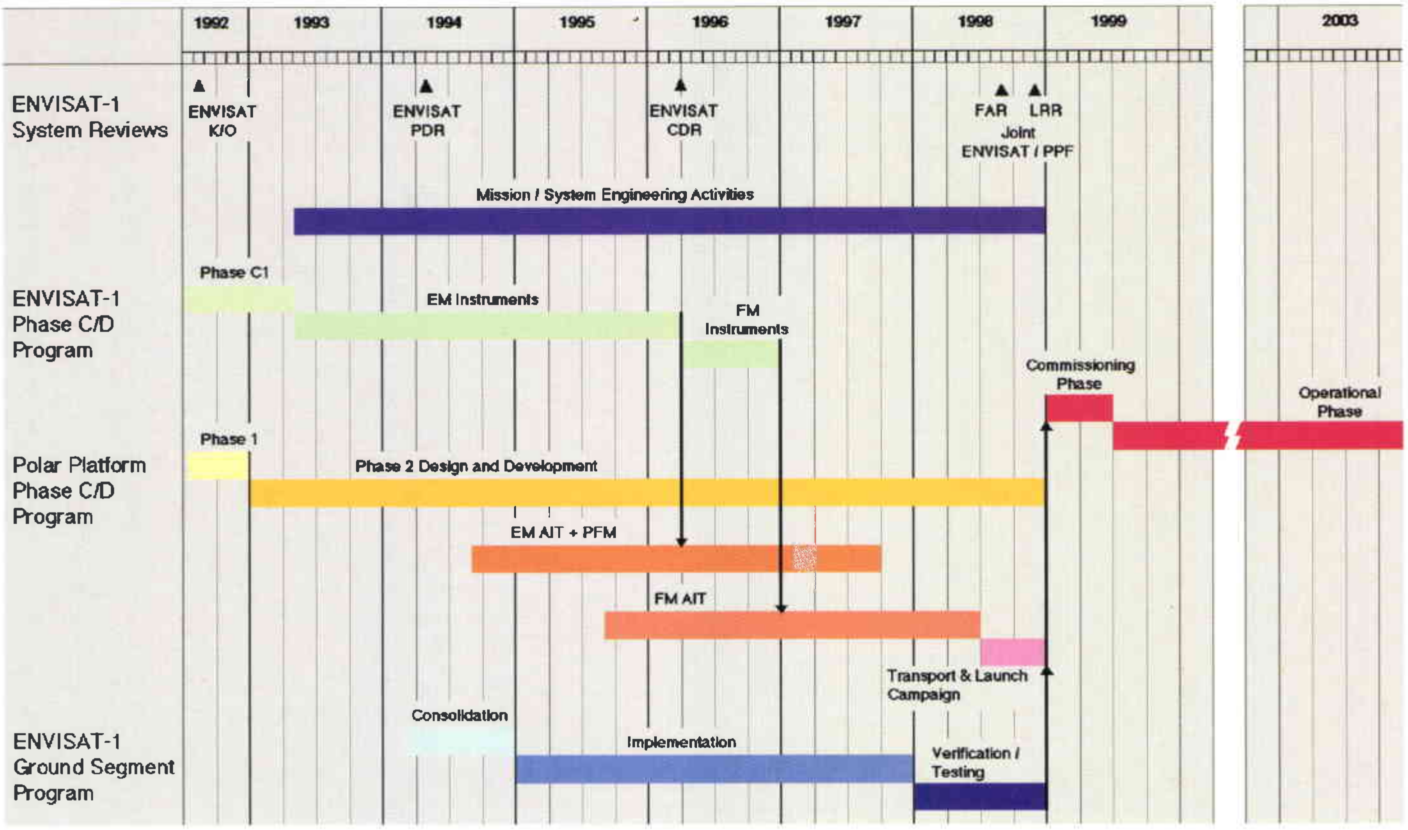


Figure 3. Envisat-1 mission summary barchart

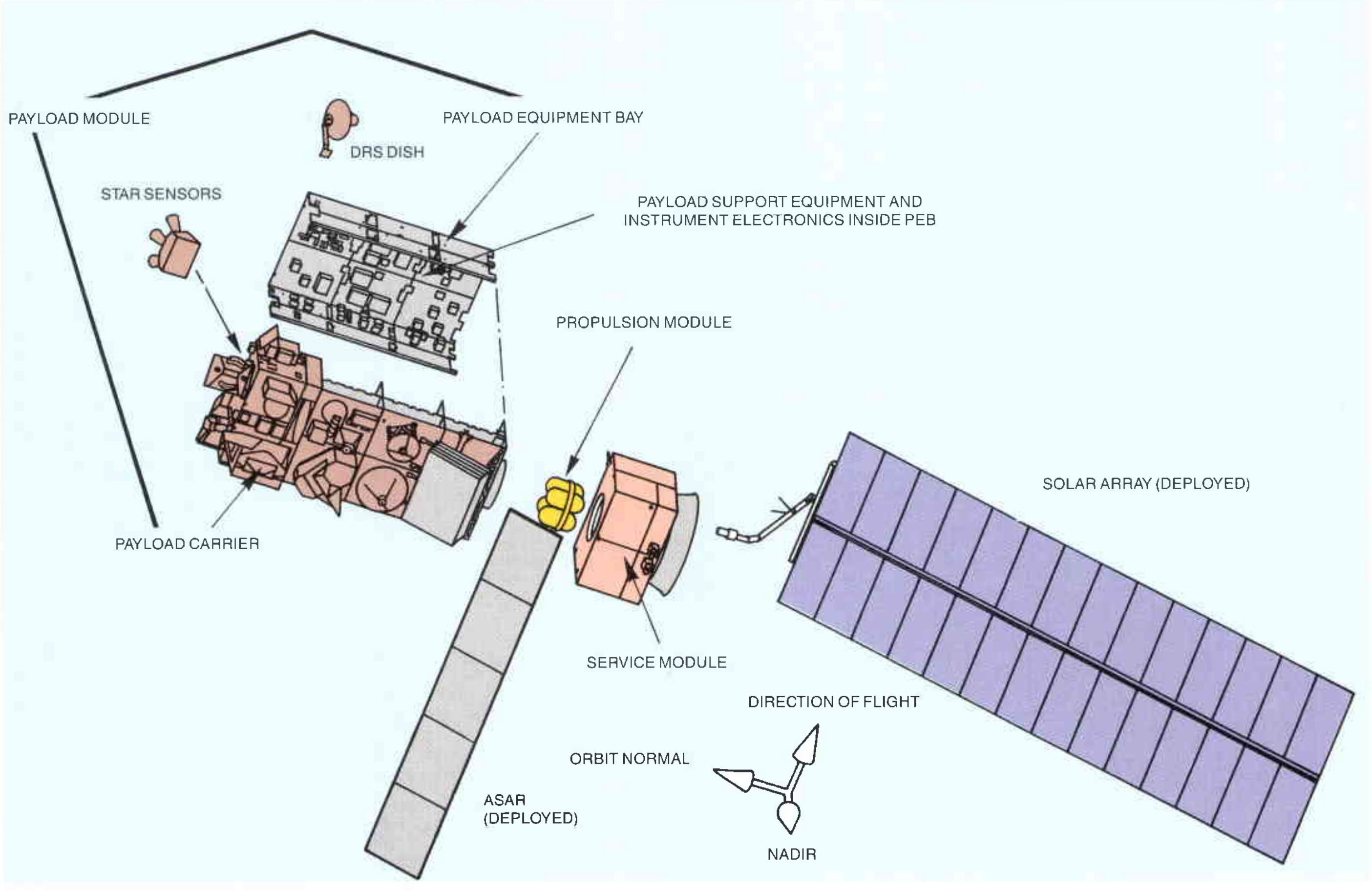


Figure 4. Envisat-1/ Polar Platform functional breakdown

the main satellite support functions, such as power, attitude and orbit control, and propulsion. It also interfaces with the launcher.
- The Payload Module, on which the Envisat instruments and PPF payload support equipment (data management and communications, electrical distribution) are accommodated.

Table 1. Polar Platform services to the payload

Mounting surface	Up to 43 m^2 externally (PLC), and 10 m^2 inside (PEB)
Mass	Up to 2000 kg of payload instruments
Power	1.9 kW average over the orbit, 2.5 kW peak power
Data handling	o One high-rate channel for ASAR (100 Mbps) o Ten medium-/low-rate (up to 32 Mbps) channels for the other instruments o Recording at 5 Mbps on up to 4 tape recorders with replay at 50 Mbps. Maximum capacity (30 Gbits) for storage of one full orbit of medium-/low-rate data
Data transmission	o Real-time high-rate together with recorded or real-time low-/medium-rate data can be down-linked simultaneously in X-band direct to ground or in Ka-band via DRS o Two (out of three) channels are provided for both Ka- and X-band, each 50/100 Mbps
Attitude	o Star-tracker-based reference system o Pointing better than 0.1° (3 σ) o Measurement better than 0.03° (3 σ)

The Payload Module in turn has two functional subassemblies in addition to the Payload Instruments proper:
- The Payload Carrier (PLC), which is the structure and harness supporting the externally mounted instruments and some PPF equipment (Ka-band antenna and star trackers). The structure is composed of four similar sections, each 1.6 m in length (five were foreseen for the multi-mission Platform).
- The Payload Equipment Bay (PEB), constituted by the equipment (belonging to either platform or instruments) mounted internally on the nadir and side panels of the three lower sections of the Payload Module.

The Service Module combines a newly designed structure, thermal control and solar array with Spot-4 recurrent or partly modified hardware for the electronic equipment (AOCS, OBDH, power) and for the propulsion subsystem. It also carries a newly designed Dual-Mode Transponder (DMT), which will provide S-band communications for commanding either direct from the ground or via a Data-Relay Satellite.

The Solar Generator is made up of 14 panels (multi-mission was 16), measures 14 m x 5 m, and provides 6.5 kW of power at end-of-life.

The services offered by the Polar Platform to the payload for the Envisat-1 mission are summarised in Table 1.

Development status

The Polar Platform has now been under development for more than three years, based on the Phase-C/D Proposal received from Industry in October 1990. Since then, the detailed design work has been basically completed and the majority of the development models successfully manufactured and tested (see, for example, Fig. 5). The updates to the design resulting from the reorientation to meet the needs of the Envisat-1 mission have also been introduced.

Manufacture of the PPF structural model is currently well-advanced with the Service Module completed and due to enter static qualification testing this autumn.

A Preliminary Design Review (PDR) has been performed by the Agency in November 1992 for the multi-mission Polar Platform.

The ground segment

Extensive ground facilities are required to support the Envisat-1 mission, both to command and control the satellite and to handle the very large quantities of data that will be provided by the instruments on-board. Specific efforts will be made in both of these areas, taking into account the existing ESA ground infrastructure and capitalising on the experience gained and lesson learnt from the ongoing programmes, and from ERS-1 in particular.

The command and control of the satellite is to be organised by the European Space Operations Centre (ESOC) in Darmstadt (D) using Kiruna (S) as the primary S-band station, complemented by commanding via DRS.

The handling of the payload data is to be organised by ESRIN, with both X-band and DRS reception facilities being used. Processing of data within the Envisat-1 Ground Segment itself will be limited, with only engineering data, calibrated by instrument, being provided in most cases.

Clearly, the end users of the Envisat-1 data will need data that have been further processed to provide a range of geophysical data products. Intensive discussions are

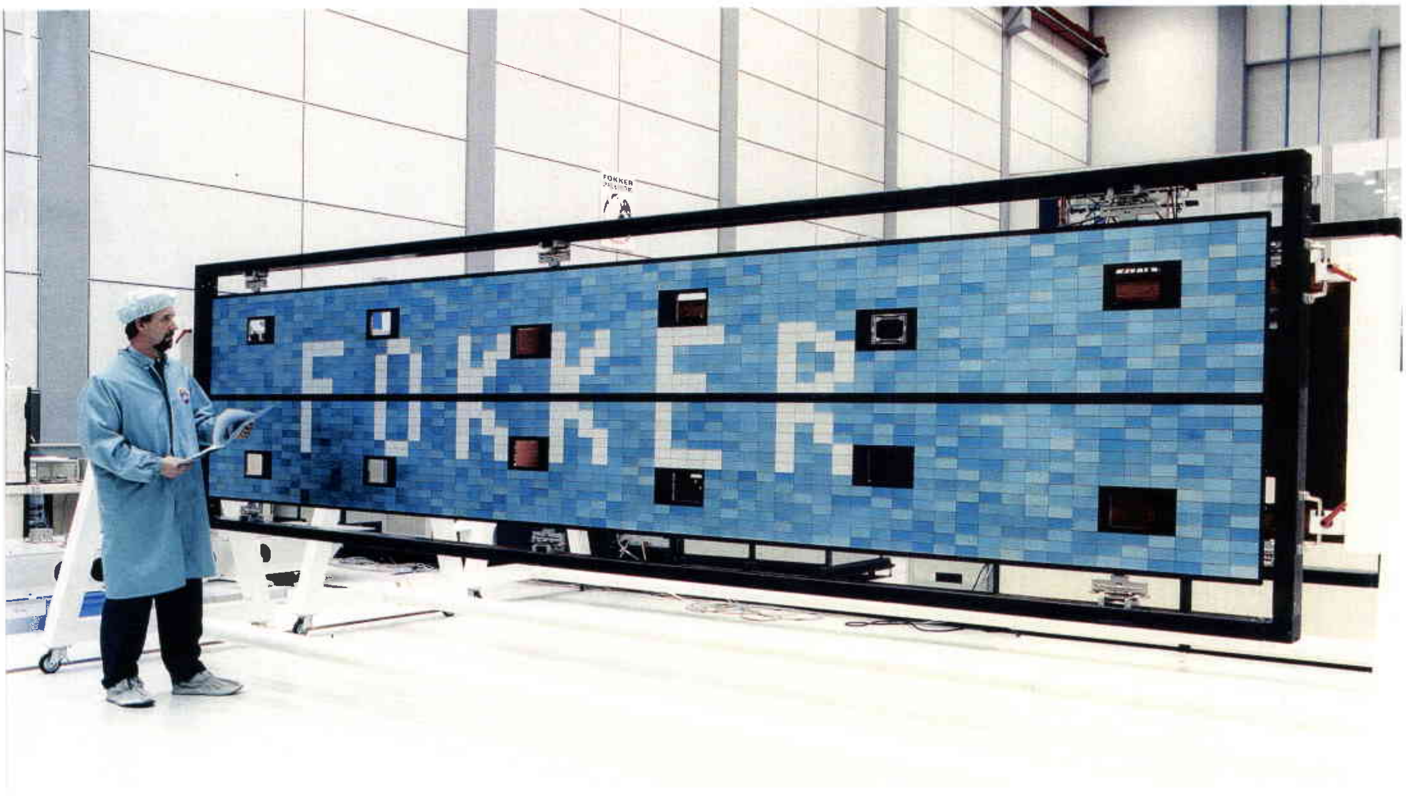


Figure 5. A Polar Platform solar-array panel under test

currently taking place within the European User Community to determine the best way to ensure that such geophysical products can be made easily available to the widest possible community.

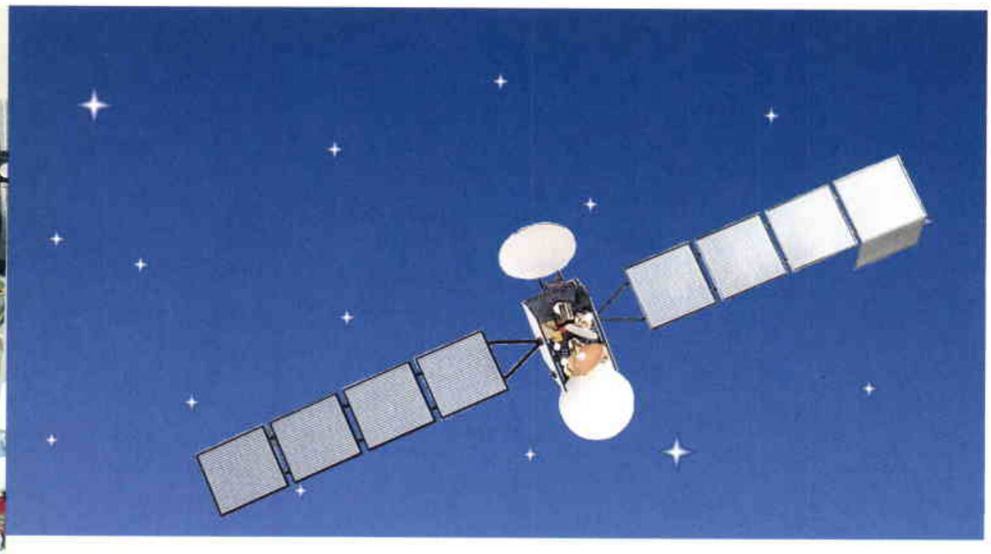
The solution eventually implemented will make use of facilities owned and operated by ESA's Member States, facilities to be implemented as part of the Agency's Data User Programme, and possibly also facilities owned and operated by the European Community.

The overall infrastructure will be supported by a wide circle of scientific endeavours in order to optimise the overall data processing and obtain the maximum amount of useful information from Envisat-1's instruments.

Conclusion

For the Earth-Observation User Community, the Envisat-1 mission will provide invaluable data for a broad field of applications, leading to a better understanding of the Earth's environment, its climate and the ecological consequences of human activities on a global scale.

The mission represents a major challenge for ESA in that it combines the efforts of two of its major programmes, namely the Envisat-1 and PPF Programmes. The overall system is complex, from both the technical and organisational points of view, with a large number of interfaces and very ambitious goals. It is also, therefore, a challenging task for the companies that make up the Polar Platform and Envisat-1 Industrial Consortia.



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Envisat-1: Europe's Major Contribution to Earth Observation for the Late Nineties

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Following ERS-1's success and the endorsement of the Agency's Earth-Observation Programme by the European Ministers at their meetings in Munich (1991) and in Granada (1992), ESA is now moving ahead with the implementation of an ambitious programme for Earth observation. This article provides an overview of one aspect of this programme, namely the Envisat-1 mission planned for launch in 1998.

Introduction

Coupled with increasing international concern over the Earth's environment is the acceptance of the need to achieve a better understanding of our Earth/atmosphere system and the factors that influence it. Basic to the realisation of this objective is the provision of data. These data are required not only to monitor the state of the Earth system and to detect changes, but also to provide the better scientific understanding needed to identify processes and validate models.

For the provision of these data, man must look to space. Surface or airborne data generally lacks the geographical coverage and repetitivity required. Provision of space data, however, implies a long-term commitment on the part of space agencies as continuity of data is essential. These needs are recognised in the Earth-Observation Programme proposed by ESA, which was endorsed by the Ministers of the Member States in November 1991 and re-affirmed in November 1992.

Underlying this programme is the Agency's Earth-observation strategy, which was enunciated in collaboration with the user community and representatives of the ESA Member States. This identifies four basic objectives, namely:

- Monitoring of the Earth's environment on various scales, from local or regional to global.
- Management and monitoring of the Earth's resources, both renewable and non-renewable.
- Continuation and improvement of the service provided to the worldwide operational meteorological community.
- Contributing to the understanding of the structure and dynamics of the Earth's crust and interior.

The realisation of these objectives forms the basis of the ESA Earth-Observation Programme.

To address the themes underlying the Agency's Earth-observation strategy, global data sets, in many cases spanning decades, are required. These data must cover a wide range of disciplines as the themes generally span traditional lines of demarcation. Furthermore, given the synergism between both the disciplines and the instruments necessary to realise the objectives, missions will in general have to be broader and carry more instruments than has been the case in the past.

Consideration of the implications of trying to meet these various criteria led the Agency to conclude that it could make a major contribution to the basic objectives of its Earth-Observation Programme by implementing a series of missions in polar orbit, exploiting the capabilities of the European Polar Platform. Two such series of missions are currently proposed, both in 'morning' orbits:

- The Envisat missions, which are concerned with research objectives and the flight of pre-operational instruments.
- The Metop missions, which focus on the needs of operational meteorology and climate monitoring.

This article is concerned specifically with the first of the Envisat missions, scheduled for launch in 1998, and the objectives underlying it. The accompanying series of articles describe some of the individual Envisat instruments in greater detail.

The Envisat-1 mission objectives

In considering the possible orientation of the first of the Polar Platform missions, namely Envisat-1, particular note was taken of increasing concerns over the Earth's atmosphere and its environment and the possibility that it may be being adversely affected by mankind's activities (Fig. 1).

These concerns have led to the establishment of international endeavours such as the World Climate Research Programme (WCRP) and the International Geosphere/Biosphere Programme (IGBP).

on the experience gained from the ERS missions, extending and consolidating the range of parameters observed. It is intended that Envisat-1 should consolidate the ERS operational mission, and here special mention should be made of the operational monitoring of sea ice.

To realise these objectives, it is necessary to observe a wide range of parameters, which can be loosely grouped according to whether the variable relates to the atmosphere, the land, the ocean, or snow and ice. The relation between mission objectives and geophysical parameters is summarised in Table 1. The Envisat-1 payload has been chosen to observe as many of the relevant parameters as possible within the overall mission constraints.

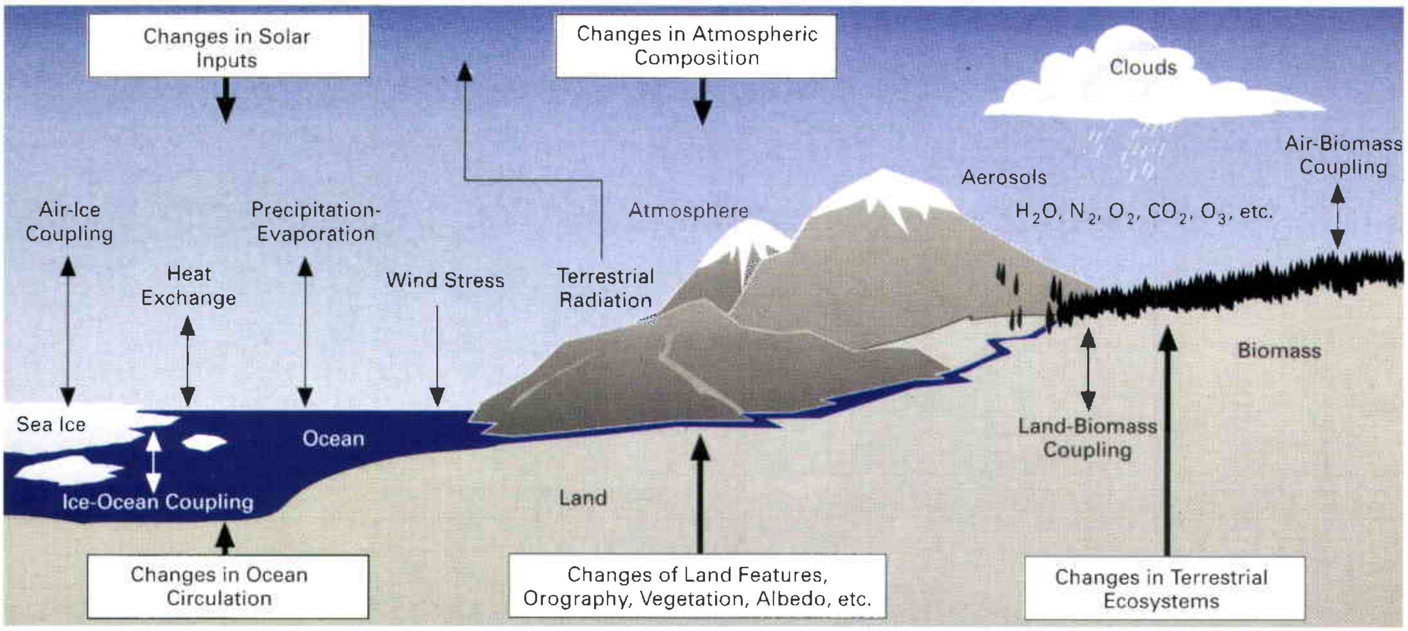


Figure 1. Schematic of the principal components and interactions in the global climate system

It was therefore decided that Envisat-1 should focus, as a prime objective, on making a significant contribution to environmental studies, notably in the areas of atmospheric chemistry and ocean/ice studies (including marine biology of the ocean surface). By so doing, in addition to providing data relevant to the monitoring of the state of the Earth's climate, it should help to increase understanding of the various processes involved, which is a pre-requisite for the development of better climate models. As secondary objectives, Envisat-1 should also seek to:

(a) enhance the capability to monitor and manage the Earth's resources, and

(b) contribute to a better understanding of solid-Earth processes.

Envisat-1 should also seek to capitalise

The realisation of mission objectives

Eleven instruments will be flown on Envisat-1 (Table 2), which together provide the means to realise the mission objectives. Of course, the instruments themselves only produce engineering data but, when combined with geophysical models and processed with appropriate algorithms, these can be used to estimate the pertinent geophysical parameters.

For example, it is not possible to observe directly the divergence of the incoming solar radiation through the atmosphere. However, this can be derived with the aid of models and the observation of parameters such as the radiation flux at the top of the atmosphere, the vertical profiles of temperature and water vapour, and the distribution and characteristics of clouds and aerosols. Several other examples could be cited.

Table 1. Relationship between mission objectives and geophysical parameters

		Primary Objectives			Secondary Objectives	
Disciplines	Geophysical Phenomena	Environment	Atmosphere	Ocean and ice	Earth resources	Solid Earth
Atmosphere	Clouds	P	P			
	Humidity	P	P			
	Radiative fluxes (top of the atmosphere)	P	P			
	Temperature	P	P			
	Trace gases	P	P			
	Troposphere	P	P			
	Middle atmosphere	P	P			
	Aerosols					
Land	Surface temperature	P			S	
	Vegetation characteristics	P			S	
	Surface elevation	S			S	S
Ocean	Ocean colour	P		P	S	
	Sea surface temperature	P	P	P	S	
	Surface topography	P		P		S
	Turbidity	S		S	S	
	Wave characteristics	P	S	S		
	Wind speed	S	P	P		
Ice/Snow	Extent	P	P	P	S	
	Snow cover	P	S	P	S	
	Topography	P		S		S
	Temperature	P	S	P	S	

P = Primary Need; S = Secondary Need

The geophysical parameters that may be derived from each instrument are summarised in Table 3. This shows that the complement of instruments included in the Envisat-1 mission provides a balanced approach in addressing the mission objectives. It can also be seen that, although the data from the various instruments are focussed on the primary mission objectives, secondary mission objectives are not neglected.

The atmosphere

For the primary objective, in the atmosphere, the payload will provide data to quantitatively monitor radiative processes, air/sea interaction and interactions between the atmosphere and land and ice/snow surfaces, as well as the formation and evolution of clouds. It will also provide data that can be used to determine the atmosphere's composition and to study the associated chemical processes. This includes the observation of the ozone anomaly (Fig. 2) detected over the Antarctic (and more recently over the Northern Hemisphere).

Important processes occur throughout the atmosphere and so to study them data must be gathered at all of its levels, including the troposphere (Fig. 3). In particular, recent work has highlighted the need to observe the chemistry of the tropshere, a region notoriously difficult to observe from space.

Observations will be possible in the troposphere as well as in higher regions of the atmosphere. Many of these data

Table 2. The Envisat-1 instruments

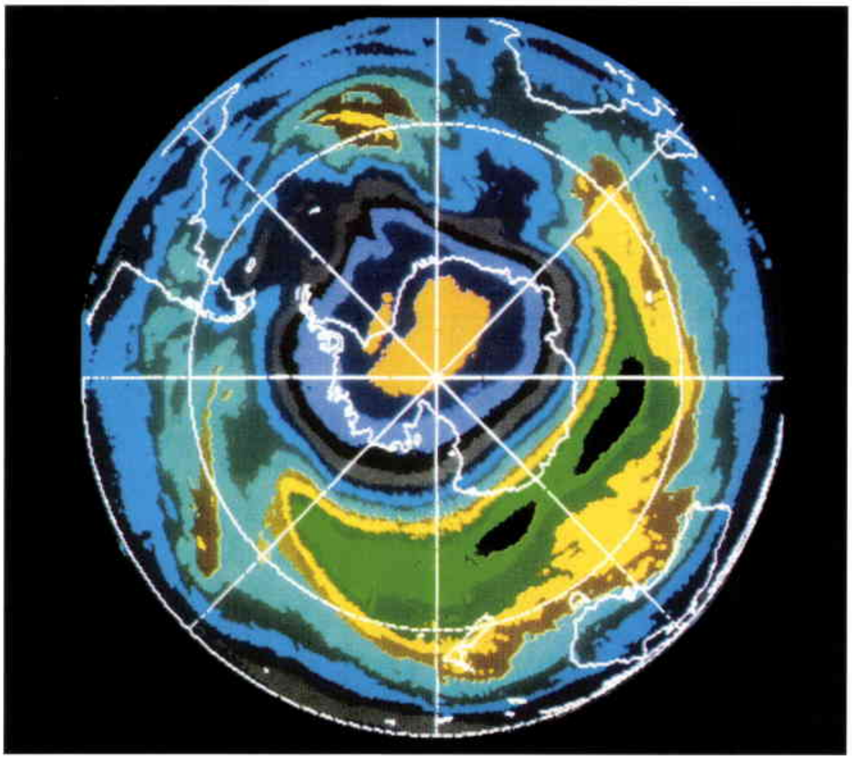
AATSR	Advanced Along-Track Scanning Radiometer	Optical/IR Radiometer
ASAR	Advanced Synthetic Aperture Radar	C-Band SAR
DORIS	Doppler Orbitography and Radio-positioning Integrated by Satellite	RF Orbitography
GOMOS	Global Ozone Monitoring by Occultation of Stars	UV + Optical Spectrometer
LRR	Laser Retro Reflector	Passive Optical Reflector
MERIS	Medium Resolution Imaging Spectrometer	Visible and Near-IR Spectrometer
MIPAS	Michelson Interferometer for Passive Atmospheric Sounding	Limb-Viewing IR Interferometer
MWR	Microwave Radiometer	Two-Channel Nadir View Radiometer
RA-2	Rader Altimeter 2	Pulse Radar
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Cartography	Multi-Channel Nadir + Limb View UV/VIS/IR Spectrometers
SCARAB	Scanner for Radiation Budget	Four-Channel VIS + IR Radiometer

*Table 3. Instrument contributions to geophysical parameter estimation**

Geophysical phenomena	Instruments AATSR	ASAR	GOMOS	MERIS	MIPAS	MWR	RA-2	SCARAB	SCIAMACHY
Atmosphere									
Clouds	×	–	–	×	–	–	–	×	×
Humidity	–	–	×	–	–	×	–	–	×
Radiative fluxes	×	–	–	×	–	–	–	×	×
Temperature	–	–	×	–	×	–	–	–	×
Trace gases									
Troposphere	–	–	×	–	×	–	–	–	×
Middle Atmosphere	–	–	×	–	×	–	–	–	×
Aerosols	×	–	×	×	×	–	–	–	×
Land									
Surface temperature	×	–	–	–	–	–	–	–	–
Vegetation characteristics	×	×	–	×	–	–	–	–	–
Surface elevation	–	×	–	–	–	–	×	–	–
Ocean									
Ocean colour	–	–	–	×	–	–	–	–	–
Sea surface temperature	×	–	–	–	–	–	–	–	–
Surface topography	–	×	–	–	–	–	×	–	–
Turbidity	–	–	–	×	–	–	–	–	–
Wave characteristics	–	×	–	–	–	–	×	–	–
Wind speed	–	–	–	–	–	–	×	–	–
Ice/Snow									
Extent	–	×	–	×	–	–	–	–	–
Snow cover	×	×	–	×	–	–	–	–	–
Topography	–	×	–	–	–	–	×	–	–
Temperature	×	–	–	–	–	–	–	–	–

* The payload will also include DORIS, which will allow precise determination of the satellite's orbit in support of other instruments.

Figure 2. Total ozone concentration in the atmosphere over Antarctica as measured by the TOMS instrument



are unique and can be used not only to investigate the 'greenhouse' effect and other aspects of the Earth's energy balance, but also to further our knowledge and understanding of the chemistry of the atmosphere. Combining the data from all three chemistry instruments means that it will not only be possible to contribute to the monitoring and climatology of key trace species, but also to validate chemical process models.

On the slightly shorter time scale, the data can be used to detect short-term variations in important climate variables, such as those in aerosol concentrations caused by volcanic eruptions, or those in trace-gas distributions arising from man's activities. It will be possible to detect changes in the troposphere as well as at higher levels of the atmosphere.

Ocean/ice

As well as providing the means to study transfers of energy and momentum between ocean and atmosphere, the instruments will allow the dynamics of the ocean surface to be monitored. The payload provides the means to make highly accurate determinations of sea-surface topography and continuous and global measurements of wind speed, wave and temperature fields. This information is of vital importance for climate studies as the oceans transport a significant fraction of the total heat energy of the Earth's system between the equator and the poles. They therefore play a vital role in the Earth's climate system.

It will also be possible to monitor ice sheets and sea-ice in terms of areal extent, surface elevation, albedo and temperature. This will allow changes in the volume of the polar ice sheets, which affect both sea level and climate, to be determined (Fig. 4). Knowledge of the mass balance of the Arctic and Antarctic ice sheets allows the prediction of probable ice-sheet responses to temperature increases arising from changes in the concentrations of 'greenhouse' gases in the atmosphere plus associated changes in sea level.

On a shorter time scale, it will be possible to detect the spread of natural and man-made pollution (e.g. oil spills) over oceans, as well as the presence of algae and plankton on the sea surface. The latter is of course also relevant to the study of air/sea transfers as 'ocean colour' is closely linked to biological activity at the surface. This in turn is associated with the generation of trace gases.

Land surface

Modelling of the impact of vegetation on climate requires detailed knowledge of the characteristics of the vegetation itself plus the associated physical/biological processes. The instruments making up the Envisat-1 payload will provide the data to allow the estimation, on a global scale, of surface albedos, vegetation cover (Fig. 5), vegetation characteristics, surface roughness, etc. All of these data correlate with the surface energy and water budgets and the transfer of trace species between the land surface and the atmosphere, contributing to the prime objectives of the mission.

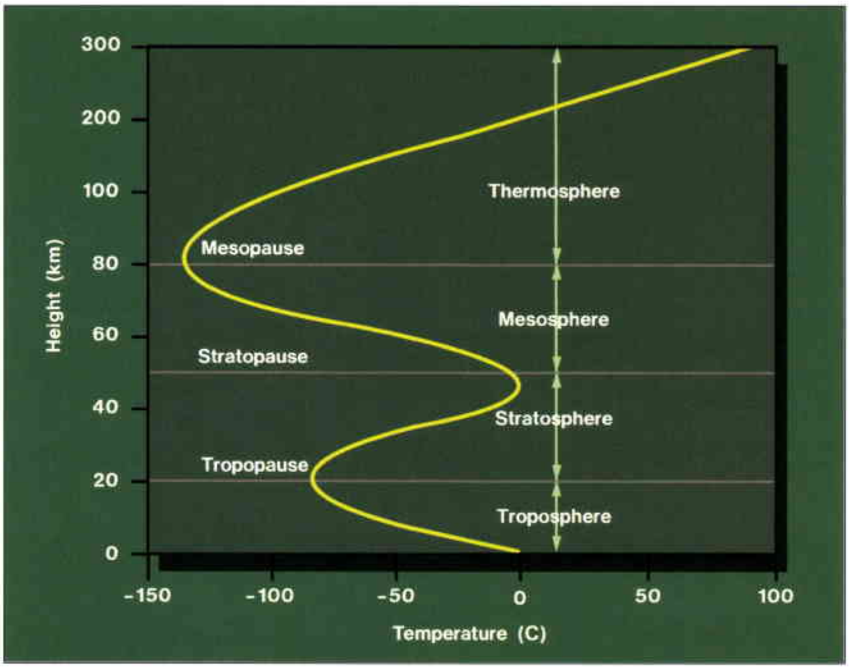


Figure 3. Variation of atmospheric temperature with height, delineating four atmospheric layers: troposphere, stratosphere, mesospere and thermosphere

The Envisat instruments will also provide data enabling land areas damaged or transformed by erosion, desert encroachment, deforestation, etc., to be monitored. Again these data are of fundamental importance to environmental studies and climate monitoring.

Secondary objectives

Land resource management and monitoring have not been neglected. Significant contributions should be provided by the large field of view, medium-resolution optical sensors and the high-resolution, all-weather imaging synthetic-aperture radar. Specific uses of these data will range from the large-scale monitoring of vegetated, semi-arid and arid areas, to regional monitoring of crops, forests and mineral resources.

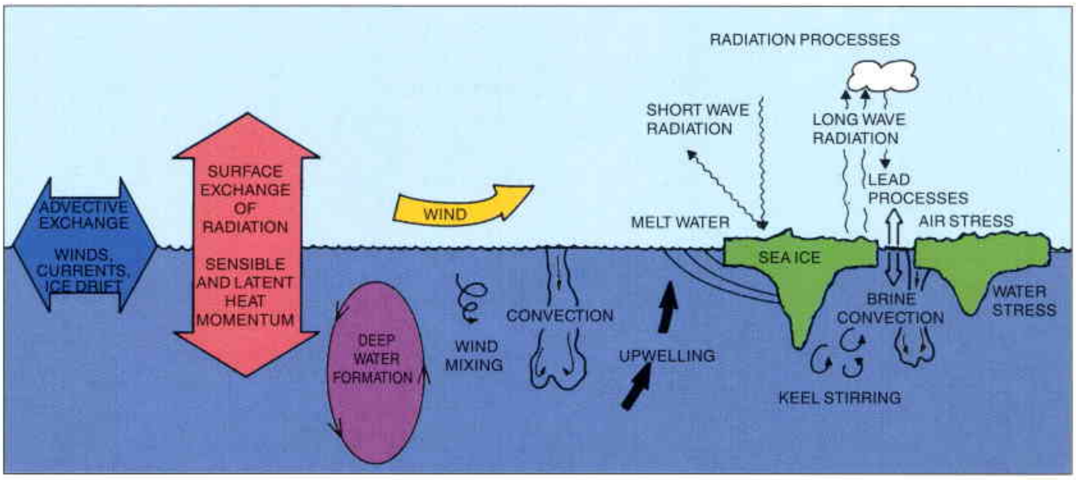


Figure 4. Air/sea-ice/ocean exchange processes (after P. Lemke)

Figure 5. Remote-sensing forest map of Europe, an ESA contribution to the World Forest Watch

Envisat-1 will also make significant contributions to studies of the solid-Earth via the provision of data of importance to geodesy and geodynamics. This stems from its ability to determine the orbit of the Polar Platform with centimetre accuracy. It will also measure surface topography over both land and water.

Instruments

We will now review the individual instruments selected for the Envisat-1 payload, the most significant of which are described in greater detail in the companion articles in this Bulletin. The ERS instruments referred to were described in the February 1991 issue. Table 3 provides an overview of the link between the requisite geophysical parameters and instrument performance.

The Advanced Along-Track Scanning Radiometer (AATSR)

The AATSR is an advanced version of the ATSR instrument successfully operating on ERS-1 (Figs. 6 & 7).

The primary objective of the ATSR instrument on ERS-1 is to measure global sea-surface temperatures for climate research and monitoring purposes. Its absolute accuracy is better than 0.5 K, averaged over areas of 50 km x 50 km, assuming that 20% of the pixels within an area are cloud-free. For cloud-free pixels of area 1 km x 1 km, the relative accuracy is about 0.1 K.

The AATSR will have a similar performance to the ATSR, but its capability will be extended by the addition of three visible channels, enabling it to observe land-surface parameters such as temperature and vegetation characteristics. Its performance is almost identical to that of the ATSR-2 on ERS-2. Measurement continuity will therefore be assured from the launch of ERS-1 in 1991 until at least 2003.

The AATSR performs a conical scan with only those parts of the cone that fall inside the 500 km-wide ground swath being sampled. The rearward part of the scan cone views the satellite ground track approximately at nadir, while the forward part of the scan looks about 47° away from the nadir. As a

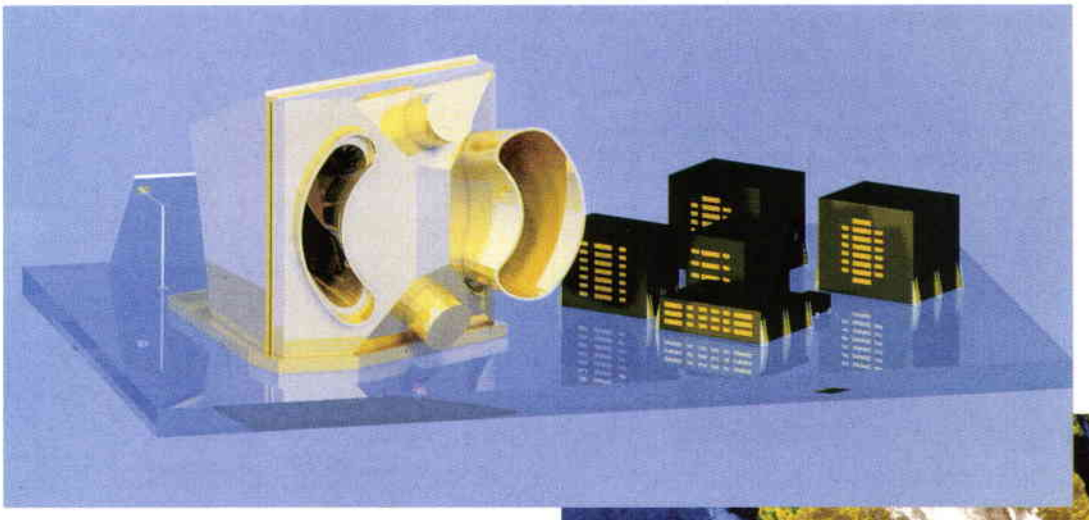


Figure 6. Computer graphic of the AATSR instrument

result, the AATSR produces two superimposed 500 km-wide images, one from the nadir view and one from the forward view. Combining the two views, which involve different atmosphere path lengths, enables corrections to be made for atmospheric effects.

Light from the instantaneous field of view is collected simultaneously by seven detectors. Four of these correspond to the infrared detectors as used on ERS-1, i.e. 3.7, 1.61, 10.85 and 12.0 micron. The other three detectors correspond to visible channels at 555, 659 and 865 nm, respectively.

The scan period outside the swath is used to view black bodies forming part of the instrument, which provide hot and cold references. This part of the scan also views a visible calibration target illuminated by the Sun during some parts of the orbit. Combining these calibration facilities with the instrument's viewing characteristics and detectors cooled to 70 K (with Stirling-cycle coolers), enables the instrument to meet its mission specification.

The Advanced Synthetic Aperture Radar (ASAR)

Although the ASAR can be regarded as a derivative of the SAR on ERS-1, it exploits more advanced technology and as a result has a much more flexible operational capability. The basic principle of operation is, however, the same as that of the ERS Active Microwave Instrument, and the ASAR also operates at C-band (5.331 GHz) like the ERS AMI.

The ASAR will make all-weather observations of surface characteristics, from which one can derive measures of wave characteristics, sea-ice characteristics (Fig. 8) and distribution, and land-surface characteristics, including estimates of soil moisture. Its multiple viewing modes, coupled with its ability to vary the polarisation of both the transmitted and received signals, significantly enhances the usefulness of the information provided because the characteristics of many of the surface features vary with incidence angle and polarisation.

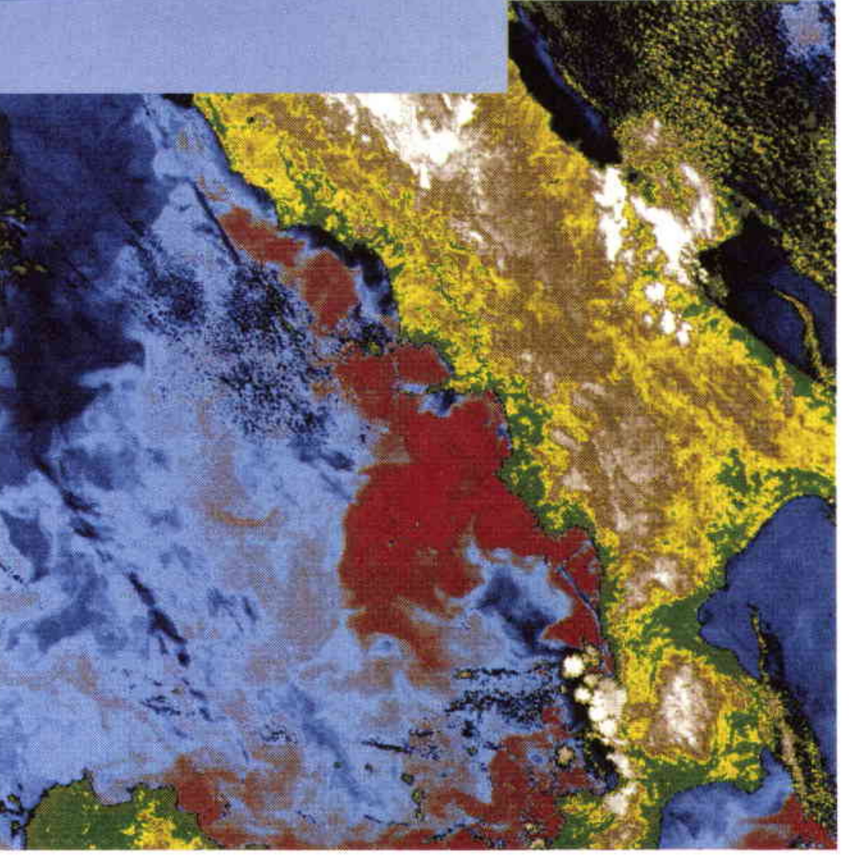


Figure 7. ERS-1 Along-Track Scanning Radiometer (ATSR) brightness-temperature image of Central Italy

The ERS-1 AMI uses a travelling wave tube to generate the radio-frequency power. This is transmitted through an antenna made of slotted waveguides. In contrast, the ASAR uses an active antenna, within which 320 identical transmit/receive modules are connected to copper transmitting patches arranged into a total of 20 'tiles'. The phase and gain of each transmit/receive module can be individually controlled. This allows a degree of control over the antenna beam, which is impossible with a passive antenna.

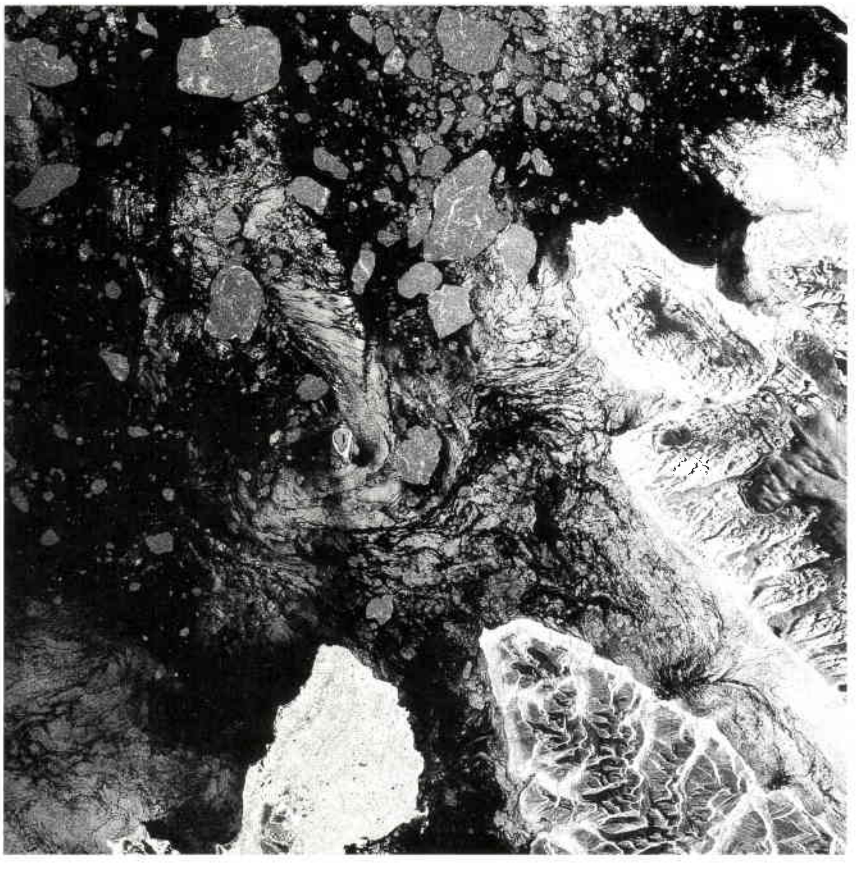


Figure 8. ERS-1 SAR image covering an area of approximately 95 x 95 km^2 around Spitzbergen's (N) northern shores, which are dominated by high mountains with large glaciers. The light-grey areas are ice floes drifting in the sea

Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS)

DORIS is a microwave Doppler tracking system which can be used to determine a satellite's exact position in space. Versions of this instrument are currently flying on both Spot-2 and Topex–Poseidon missions, and it is also planned to fly it on Spot-4 and Spot-5.

Precise positioning is of fundamental importance to several aspects of the Envisat-1 mission. In particular, RA-2 (see below) only measures instantaneous altitude, while to use this data on a global scale requires a precise knowledge of the orbit. Without DORIS, radial position errors would be of the order of 2 m. This would undermine many of the missions of RA-2, including large-scale oceanography, global and basin-scale circulation studies, as well as the global monitoring of changes in sea level. It would also be impossible to monitor the mass balance of the Antarctic ice-sheet. The solid-Earth mission (Table 1) is also particularly dependent on the information provided by the DORIS system.

DORIS measures the Doppler frequency shifts of both VHF and S-band signals transmitted by ground beacons. Instrument noise is equivalent to an error of about 0.5 mm/s in radial velocity, corresponding to absolute determinations of position to about 10 cm. The precise measurement is made at S-band, with the VHF signal being used to correct for ionospheric effects.

There is currently a ground network of about fifty stations distributed around the globe and this network is growing steadily. In its existing form, the network would provide about 75% global coverage for Envisat-1. The gaps in coverage occur at a variety of latitudes, but consist of short segments in otherwise well-covered areas. Consequently, it will be possible to recover the orbit to a high degree of accuracy.

Global Ozone Monitoring by Occultation of Stars (GOMOS)

GOMOS is a limb-viewing instrument which has been designed to use stellar occultation to measure trace-gas concentrations – notably ozone – and other atmospheric parameters in the altitude range between 20 and 100 km. By observing stars, it is intended to obtain improved geographic coverage compared with systems exploiting solar occultation such as SAGE, whilst still retaining the inherent accuracy of the occultation technique.

GOMOS measures atmospheric transmission as a function of altitude at wavelengths between 250 and 950 nm by measuring the spectrum of a star. Measurements are made both without an intervening atmosphere and as the star sets through the atmosphere. From these observations it will be possible to derive vertical profiles of ozone, several of the oxides of nitrogen, water vapour and temperature, as well as of aerosols between the upper troposphere and higher levels of the atmosphere. Global coverage will be quite extensive as several hundred stars will be observed each day. GOMOS data will complement those of MIPAS and SCIAMACHY, by providing very-high-accuracy observations, particularly of ozone.

The instrument consists of a steerable mirror feeding a telescope, which in turn feeds light two spectrometers, one operating in the ultraviolet/visible (250–675 nm), and one in the infrared (756–773 and 926–952 nm). The steerable mirror is used to acquire and then track stars as they set through the atmosphere. About 25 stars are bright enough to be routinely observed, at different longitudes, from each orbit.

The Laser Retro-Reflector (LRR)

The LRR is a set of passive reflectors designed to allow ground-based laser stations to measure the range to the spacecraft precisely. It will be used to complement the DORIS instrument for the restitution of the precise Envisat-1 orbit.

The Medium-Resolution Imaging Spectrometer (MERIS)
MERIS is a push-broom imaging spectrometer covering the spectral range 400–1050 nm. Within this range, up to fifteen different spectral bands may be chosen (they are programmable). It has a wide ground swath (ca. 1500 km), subdivided into six separate segments, with resolution at the subsatellite point of up to 0.25 x 0.25 km^2. At low resolution, this becomes 1 x 1 km^2. It has a robust calibration system.

The primary mission of MERIS is to measure 'ocean colour', i.e. chlorophyll and other suspended matter (Fig. 9), but it can also be used for the observation and mapping of:

- Oceans: pollution, coastal effects and sea ice.
- Land: vegetation, inland water, agriculture, forestry, snow and ice.
- Atmosphere: cloud characteristics, water-vapour content and aerosols.

As can be seen from Table 3, MERIS is a very flexible instrument providing data of relevance to both primary and secondary Envisat-1 mission objectives.

The Michelson Interferometer for Passive Atmospheric Sounding (MIPAS)
MIPAS is a Michelson interferometer viewing in the limb. It measures emission spectra in the mid-infrared (i.e. between 4.15 and 14.6 micron) to a high spectral and radiometric accuracy. Almost all geographic regions will be accessible as it can scan the atmosphere at the horizon either at right angles to the flight direction or looking backwards along it. It will be able to observe the atmosphere between tangential heights of 5 and 150 km.

The mid-infrared region of the spectrum is rich in emission lines and so MIPAS will be able to observe a wide range of atmospheric species. These include ozone, almost the complete oxides of nitrogen family, many fluorocarbons, acetylene and ethane, carbon monoxide, methane, nitrous and nitric acid and a host of other species, plus temperature, water vapour and aerosol. It provides a data set that can be used to produce a global climatology of trace species, as well as to advance understanding in the areas of stratospheric and upper-tropospheric chemistry and atmospheric dynamics. Its data provide a very good complement to those of GOMOS and SCIAMACHY.

The Microwave Radiometer (MWR)
This is a nadir-viewing, two-channel, passive microwave radiometer operating at 23.8 and 36.5 GHz. At these two frequencies, it receives and measures microwave radiation generated and reflected by the Earth. The signals received can be related to surface temperature but, most importantly, they provide an estimate of the total water content in the atmosphere. The Microwave Radiometer has a 20 km-diameter field of view.

The MWR has a limited but very useful role, namely to provide the data required to correct the data from the Radar Altimeter (i.e. RA-2) for tropospheric effects arising from absorption by water vapour. Without the MWR data, the Altimeter would have its accuracy much reduced, making it difficult to meet its mission objectives.

The MWR instrument, which is of the same design as that on the ERS-1 and ERS-2 satellites, compares received signals with signals from a reference load at a known temperature using a Dicke switch. On-board calibration will be performed using a sky horn pointing to deep space (i.e cold calibration at 4 K), with an internal load supplying the hot reference.

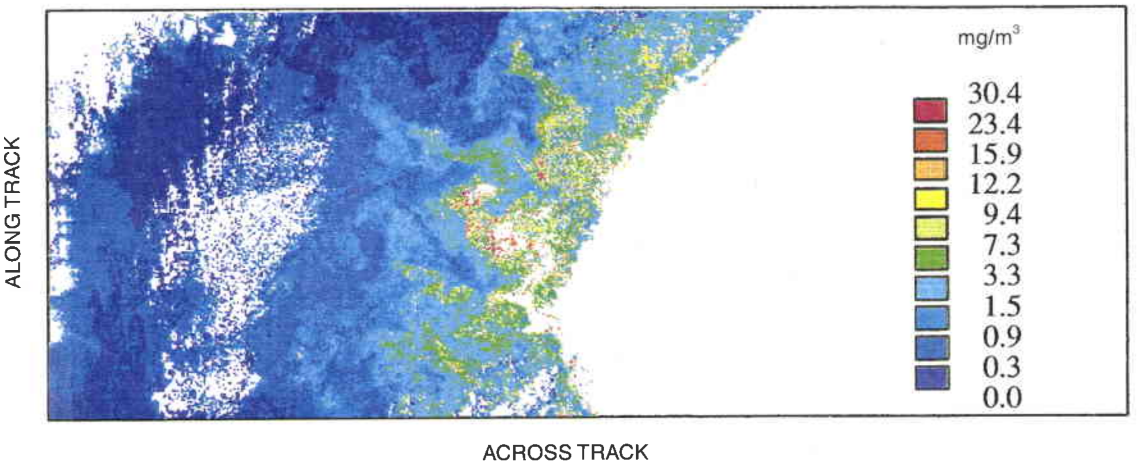


Figure 9. Chlorophyll concentration off West Africa in winter derived from the US Coastal Zone Colour Scanner (CZCS) instrument (white patterns are land or clouds)

The Radar Altimeter (RA-2)

The Radar Altimeter is a nadir-pointing pulse radar designed to make precise measurements of altitude over the entire Earth, including all types of surfaces. It measures the transit time and radar backscatter of individual transmitted pulses. The transit time is proportional to the satellite's altitude and, provided an accurate model is available of the spacecraft's orbit, the elevation of the surface over which the Altimeter was flying can be determined with great accuracy, i.e. to 10 cm or better. For this, it depends on the provision of data from both DORIS and the MWR. The magnitude and shape of the echoes returned also contain information on the characteristics of the surface that caused the reflection.

Although RA-2 cannot provide any information on atmospheric structure, it has an essential role to play in the Envisat-1 mission. Operating over oceans, its data can be used to determine ocean topography, thereby supporting research into ocean circulation (and the associated transfers of energy) and studies of basin-scale circulation as well as sea-bottom, surface and marine geoid characteristics. From the shape of the pulse, it is possible to determine sea-surface wind speeds and significant wave heights. These data are important for weather and sea-state forecasting.

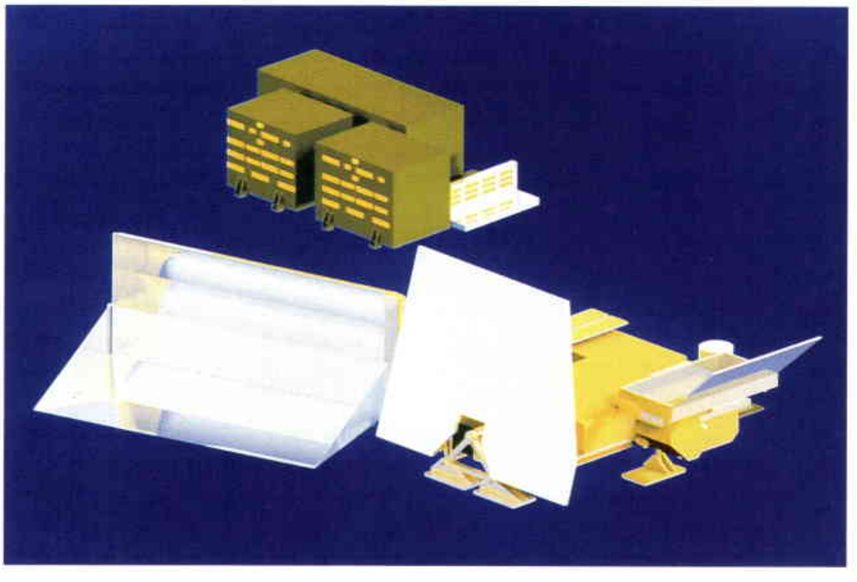


Figure 10. Computer graphic of the SCIAMACHY instrument

RA-2 is also able to map and monitor sea ice and polar ice sheets and hence the energy/mass balances of major ice sheets, including the Antarctic. Its data can also be used to observe global sea-level rise. RA-2 guarantees continuity with ERS data, thereby ensuring a long-term data set for use in climate studies. It complements the data provided by the Topex–Poseidon mission by helping to fill in many of the gaps in surface coverage that limit the accuracy with which the geoid can be determined. This knowledge is of fundamental importance for ocean-circulation studies.

In addition to operating over ocean and ice, however, RA-2 can also be used over land surfaces. This is a new feature as, from its observations of altitude and reflectivity, it is possible to determine Earth surface elevation, geological structure, and surface characteristics. Thus, RA-2 will not only contribute to the primary mission objectives, but will also makes a very significant contribution to the secondary mission objectives, including studies of the solid-Earth.

The Scanner for Radiation Budget (SCARAB)

SCARAB is a passive scanning broadband radiometer based on a French instrument flown on the Russian Meteor platform. It is expected to achieve an absolute radiometric accuracy of better than 0.5% over the four-year mission lifetime of Envisat-1.

The instrument measures radiation in four channels, corresponding to four different spectral bands:

- Total radiation: 0.2 to 50 micron
- Solar channel: 0.2 to 4 micron
- Visible channel: 0.5 to 7 micron
- Atmospheric channel: 10.5 to 12.5 micron.

By measuring the radiative fluxes of both long- and short-wave radiation at the top of the atmosphere, SCARAB will be of fundamental importance for climate studies and, most importantly, it will ensure the continuity of radiation-budget observations from the ERB experiments on Nimbus, through SCARAB on Meteor, to SCARAB on Metop.

The Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY)

SCIAMACHY (Fig. 10) is a limb- and nadir-viewing spectrometer intended to measure the abundances of atmospheric constituents in both the troposphere and the stratosphere. Solar occultation is also possible as SCIAMACHY can view both the Sun and the Moon. At the heart of the instrument is a set of eight spectrometers spanning the spectrum from 240 nm to 2.38 micron, i.e. the ultraviolet, the visible and parts of the infrared. The design of the spectrometers between 240 and 800 nm is similar to those of the GOME instrument that will be flown on ERS-2. The spectral resolution of the instrument is better than 0.25 nm in the ultraviolet, and varies from 0.22 to 1.48 nm for the visible and infrared.

The combination of fairly wide spectral coverage coupled with quite high resolution means that a number of techniques can be applied to SCIAMACHY data so that it will be possible to observe column depths and profiles of a large number of trace constituents in both the troposphere and stratosphere. These include ozone, several oxides of nitrogen, formaldehyde, methane, carbon monoxide, water vapour and sulphur dioxide, plus further species under ozone-hole conditions. It will also be able to measure temperature and to observe aerosols and Polar Stratospheric Clouds (PSCs). Its observations of the surface will also be of interest to the ocean and land communities.

SCIAMACHY will build on the experience gained with the GOME instrument on ERS-2 and will form a vital component of the Envisat-1 chemistry mission, complementing the data of both GOMOS and MIPAS. Thus, while GOMOS should provide the most accurate regular observations of ozone, those of SCIAMACHY will provide much better geographical coverage. Of particular note are the observations SCIAMACHY will make in the troposphere.

In its nadir-viewing mode SCIAMACHY has a swath that is about 1000 km wide with the minimum pixel exposure time corresponding to 32 km. In limb-scanning mode, scanning along the flight direction, the instrument will cover altitudes from 20 to 100 km with a vertical resolution of about 1 km.

In order to achieve the required radiometric performance, the visible detectors are cooled to 235 K using Peltier elements. The infrared detectors are cooled to less than 150 K using a multi-stage passive cooler. In order to limit stray light for the infrared channels, the optical bench itself will be cooled to about 253 K.

The instrument is provided with a sophisticated transputer-based data-handling system to order and compress the large quantities of data captured.

Of particular note is the robust calibration capability of the instrument, making it possible to calibrate radiometrically and spectrally in a variety of ways. This is intended to ensure that its calibration is not dependent on the characteristics of any one particular technique. In both the ultraviolet and the visible, it is possible to use the Sun, Moon and internal light sources, as well as a variety of self-consistency checks.

The spacecraft

The instruments described briefly above, and in more detail in the articles that follow,

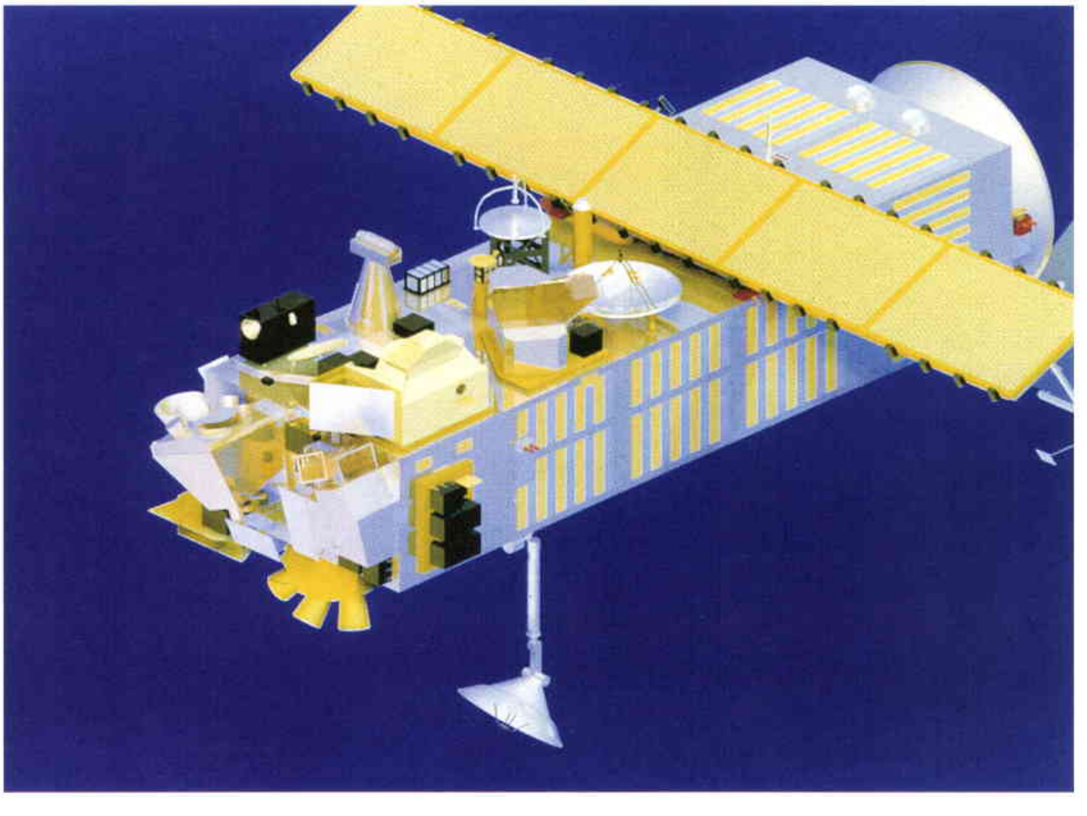


Figure 11. Computer graphic of Envisat-1

have been designed to be compatible with the European Polar Platform, which was described in the August 1992 issue of ESA Bulletin. This is a modular structure with a series of possible options, including choice of size (i.e. number of modules), power, and data recording and transmission capability. For data transmission, it can exploit the capabilities of the data-relay satellites.

The arrangement selected for the Envisat-1 mission is shown in Figure 11. It uses a four-module configuration of the Polar Platform. Further details can be found in a companion article in this Bulletin.

The orbit

Envisat-1 will be launched into a high-inclination, Sun-synchronous orbit, with a mean altitude of about 800 km. Such an orbit ensures that the local time, when the satellite is overhead, is constant for any given latitude. The particular orbit chosen for Envisat-1 is characterised by an equatorial crossing time, when travelling southwards, of 10 a.m.

The ground track of the orbit chosen as a reference (i.e. the baseline orbit) repeats precisely after 35 days, with almost complete coverage of the globe provided more rapidly depending on the swath width of the instrument in question. MERIS, for example, provides global coverage in less than 3 days.

Figure 12 shows how the ASAR's ground track, in global monitoring mode, will cover the Earth's surface after 3 days.

Other alternative orbits are possible as the average altitude of the orbit can be varied between 769 and 825 km, permitting significant changes to the orbit repeat cycle. It will be possible to make a limited number of such changes during the mission. Orbit maintenance will ensure that the deviation of the actual ground track from the nominal one is kept below 1 km, and that the mean equatorial crossing time varies by no more than 5 min from its nominal value.

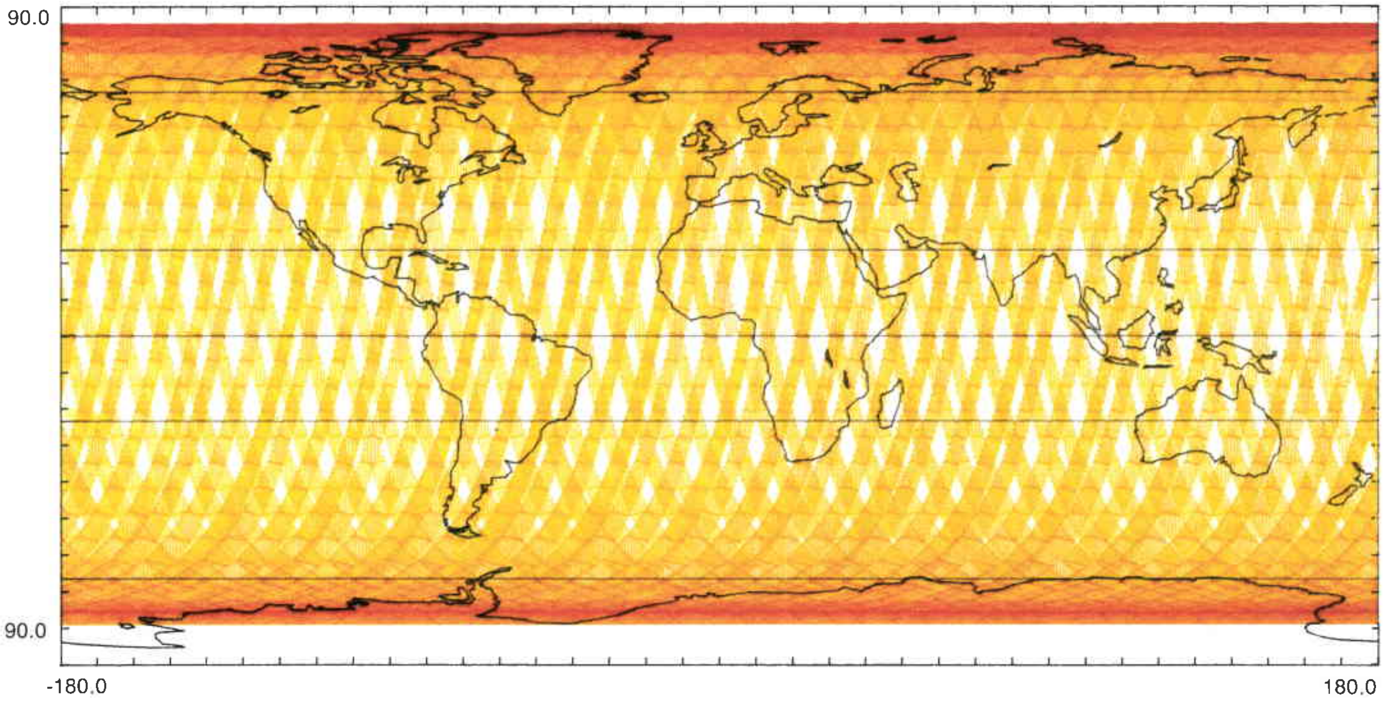
The orbit-maintenance strategy will ensure minimum disturbance for instrument operations. In-plane manoeuvres will have to be carried out about twice a month, but they should not interrupt the operation of the majority of the instruments. In addition, 'out of plane' corrections will be required every few months. These will be carried out in eclipse to avoid the risk of optical sensors being exposed to the Sun.

Communications

A major advantage of Envisat-1 compared with earlier European Earth-observation satellites such as ERS or Spot is the presence of equipment onboard to communicate with the ground via data-relay satellites. This will facilitate high-rate data coverage allowing, for example, the ASAR 100 mbit/s or the MERIS 250 m resolution imagery to be acquired over significant portions of the globe.

Figure 13 shows the areas accessible in this way using the first ESA data-relay satellite 'Artemis', when it is joined in orbit by DRS-1.

Figure 12. Three days of ASAR ground coverage (in global monitoring mode)



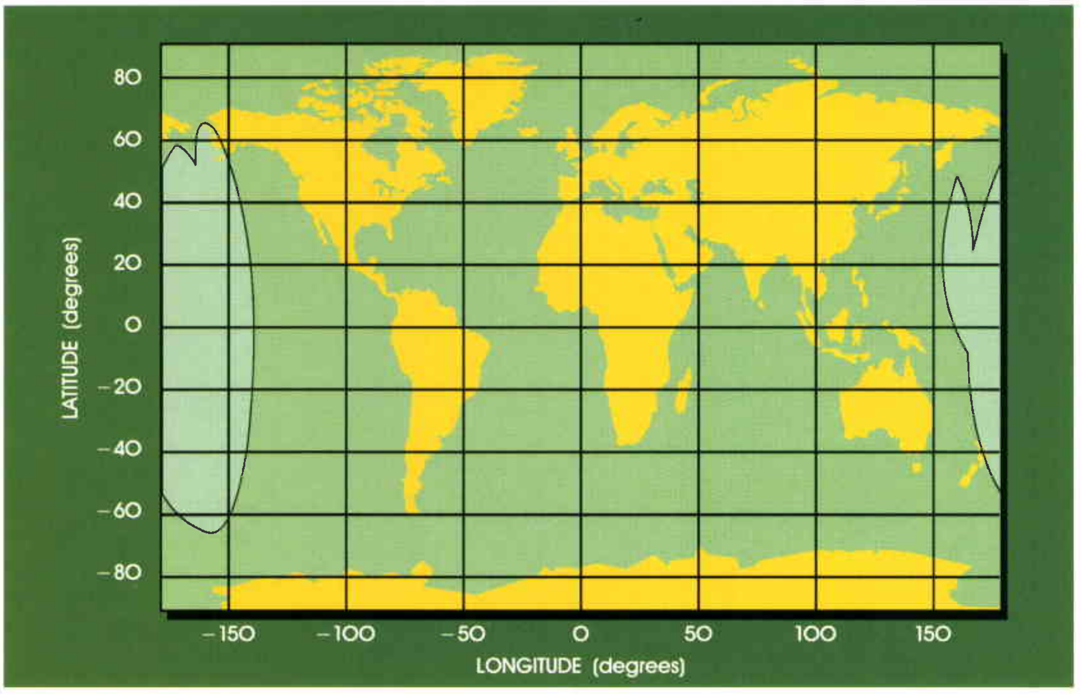


Figure 13. DRS coverage for Envisat-1. The lightest green regions are not accessible from either relay satellite

The figure shows the coverage that should be achievable when occultations due to the spacecraft and its appendages are taken into account. The ground station used to receive data down-linked from the satellite can be situated at almost any European location.

The Data-Relay Satellites also allow real-time commanding and control of Envisat whenever it is overflying the regions highlighted in Figure 13.

Envisat-1 is also equipped with a 'conventional' command and control capability operating at S-band, and a 'conventional' data downlink at X-band. These facilities can, of course, only be used when the satellite is directly over-flying the ground station concerned; typical contact times are 10 min or less for any particular ground station.

Mission profiles

Envisat-1 has been designed to permit the execution of a background operational mission which includes all instruments operating together in their low-data-rate modes. In this configuration, the composite data rate from all instruments totals about 5 Mbit/s. These data can be recorded for the entire orbit on one of the onboard tape recorders and dumped at X-band during a single pass over a ground station. Alternatively, the contents of the recorder can be dumped via the data-relay satellite.

High-data-rate operations require direct coverage to ground, either via X-band or via DRS. The satellite is designed to allow up to 30 min of ASAR high-resolution imagery per 100 min orbit. It also allows MERIS to be operated in the high-resolution mode over the whole of Europe.

Apart from these restrictions, there are no other constraints on instrument operations. In particular, it will not be necessary to limit instrument operations (with the exception of ASAR) to conserve power.

In common with the ERS and Spot satellites, the design of Envisat allows for substantial periods of autonomous operation (at least one day). Envisat-1 will be able to make essential re-configurations without further reference to the ground. For most payload contingencies, the offending instrument or instruments would automatically be switched off until ground-control staff could perform an appropriate re-configuration.

This autonomous design makes it unnecessary to be in contact with the spacecraft for more than 10 min per orbit, a requirement that can be met with a single ground-station pass.

Ground segment

There will be two major elements within the Envisat-1 ground segment, which is shown schematically in Figure 14.

The Flight Operations Segment will be responsible for spacecraft command and control. The Control Centre and its staff will be located at ESOC, in Darmstadt (D), and will rely heavily upon the facilities and expertise built up for the ERS satellites.

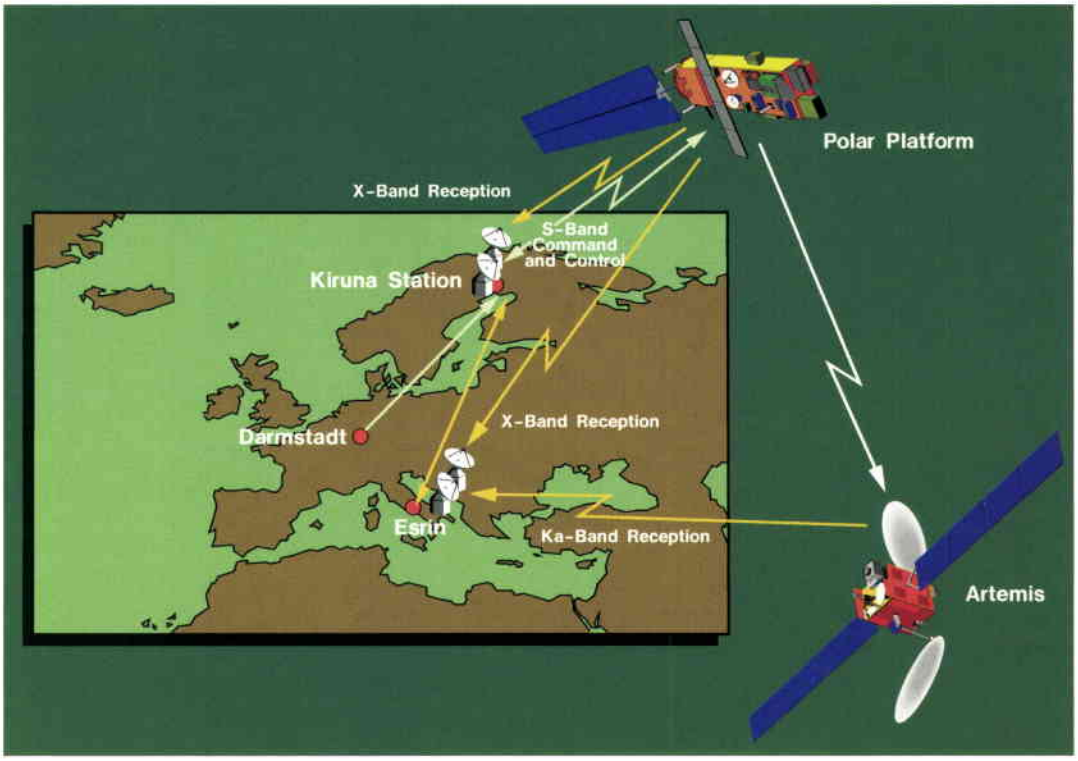


Figure 14. Envisat-1 ground-segment configuration

During nominal operations, communication with the spacecraft will be via a single command and control station situated at Kiruna, in Sweden. However, it will be possible to perform command and control activities (also at S-band) via a data-relay satellite.

The Payload Data Segment (PDS) will be responsible for overall mission planning and for the acquisition, processing, archiving and dissemination of instrument data, as well as for the provision of a centralised user service to allow users to, for example, ask for specific ASAR imagery or search the archives for data of interest. The central facility of the PDS will be located at ESRIN, Frascati, and will rely heavily on the facilities, expertise and lessons learned from the ERS satellites. The PDS will have two X-band receiving stations, one co-located with the command and control station at Kiruna, the other close to ESRIN itself.

In addition, the PDS will include a single data-relay satellite User Earth Terminal. This will also be located close to ESRIN and will allow all instrument data routed via a data-relay satellite to be received there.

The PDS will have facilities for the generation and dissemination of fast-delivery products from the majority of the Envisat-1 instruments within 3 h. It will also include facilities for the generation and delivery of more precise offline products. Raw data and products will be archived within the PDS.

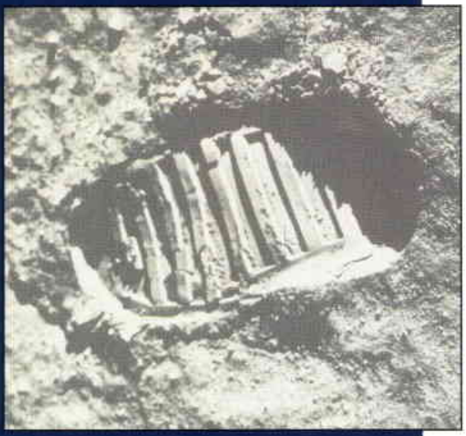
In general, the products produced by the PDS will be limited to the so-called 'Level 1B' processing, which means that the data will have been corrected for all the characterisable distortions produced by the instrument.

Clearly, in order to achieve the maximum scientific benefit from the Envisat-1 data and to realise the mission objectives, a great deal of processing beyond that conducted in the PDS will have to be performed. The Agency has established active links with a large number of national and international agencies which would be prepared to perform these activities.

Conclusion

This article has provided an overview of the Envisat-1 mission, outlining its objectives and giving outline descriptions of its instruments and their functions. The companion articles in this issue focus on the specific features and benefits of the various instruments.

Envisat-1 is the most ambitious Earth-observation mission ever proposed by the Agency and will provide a wide range of exciting opportunities for the Earth-observation User Community, especially when viewed in the context of the ERS satellites and subsequent missions such as the Metop series and Envisat-2.



Envisat's Advanced Synthetic Aperture Radar: ASAR

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An Advanced Synthetic Aperture Radar (ASAR) has been selected as the imaging radar sensor for the Envisat-1 payload. In addition to providing continuity of data with the single-swath, single-polarisation Active Microwave Instrumentation (AMI) currently flying on ERS-1 (and ERS-2), the ASAR has the additional advantages of offering: greater coverage, with more flexibility in the choice of swath positions, a wider range of incidence angles, and a wide swath capability; dual polarisation; and improved wave mode capabilities.

ASAR's role

The objectives for the Advanced SAR are very similar to those of the AMI on ERS-1 and ERS-2. The main task will again be that of monitoring the Earth's environment to collect more precise information on global change, focussing specifically on global climate and all of the factors that may influence it.

Monitoring of the Earth's bio-mass, especially the deforestation in the large primeval forests in the equatorial regions, will allow better modelling of the influence on the greenhouse effect and global climate and facilitate the implementation of countermeasures.

Desertification and the distribution of humidity, changes in water levels, flooded areas, and the extent of the ice caps around the North and South Poles are other major factors that need to be monitored in order to improve our understanding of global climate change.

Envisat's SAR images will also further improve our understanding of ocean dynamics, the interactions between oceans and atmosphere, as well as both manmade and natural processes in coastal zones.

The major advantage of using a SAR for earth-observation tasks lies in its ability to acquire imagery day or night and independent of cloud cover and weather conditions. This weather-independent capability is of vital importance for disaster assessment, as major floods or large oil spills, etc. usually occur in weather conditions that drastically curtail the usefulness of optical sensors.

ERS-1 SAR images have also proved extremely useful for shipping operations in Arctic ice. Ocean-wave spectra taken around the globe with ASAR will further improve the safety of shipping routes and offshore activities.

As experience with SAR data grows, its contribution to resource management will also become more and more important. In addition to the bio-mass estimating application already mentioned, improved classification methods will allow more accurate harvest predictions, better estimates of sweet-water resources and, via geological surveys, support the search for mineral resources.

The ASAR instrument

Given the rapid expansion in the SAR data user community, it is essential that Envisat should carry an instrument that not only provides data continuity with ERS-1 and ERS-2, but also at the same time represents a step forward in terms of both system flexibility and the scientific and operational value of its data sets.

To satisfy these needs, the ASAR design incorporates:

- a flexible swath-position capability, which will offer the choice between several image swath positions at various distances from the subsatellite track with different incidence angles

– a dual-polarisation facility (cf. vertical only on ERS), offering horizontal- or vertical-polarisation imaging.

The ASAR's ability to switch between different swaths offers very fast multiplexing, so that an overall swath more than 400 km wide can be imaged in one pass. In addition to this so-called 'Wide Swath Mode', the ASAR can be set to operate at a coarse spatial resolution of only 1000 m. The data rate will then be low enough for tape recording onboard the spacecraft. This is known as the 'Global Monitoring Mode' and it constitutes a tool for monitoring such features as ice coverage, snow coverage, deforestation, desertification or humidity, without interruption and on a global scale, due to its independence from ground-station coverage.

The ASAR's ability to switch between two polarisations allows a special 'Alternating Polarisation Mode' to be implemented which permits half of the looks at a scene to be acquired with a horizontal, and the other half with a vertical polarisation in a single pass, thereby considerably increasing the target classification capability (especially if used in conjunction with multi-temporal imaging of the same scene).

Furthermore ASAR will, like ERS, have a 'Wave Mode' for taking 5 x 5 km images but more frequently, over 100 or 200 km distances, and with two such images in any swath over the oceans, to supply ocean-wave spectra on a global basis.

As Figure 1 shows, the ASAR instrument is divided functionally into two sub-assemblies:
– an Antenna Sub-Assembly (ASA), containing the phased-array antenna electronics distributed over 20 'tiles', and
– a Central Electronics Sub-Assembly (CESA), providing signal (RF) generation and reception, control signals, power conditioning and data formatting.

The physical configuration of the spacecraft is shown in Figure 2, where it can be seen that the ASAR antenna consists of five hinged panels, each containing four tiles.

The CESA equipment units are mounted on three of the Payload Equipment Bay panels inside the spacecraft.

Control of the instrument covers the following functions:
– Selecting the required mode and generating the appropriate timeline.
– Selecting the required antenna beam pattern for the required swath (or beam patterns in modes where multiple swaths are needed).
– Housekeeping, including setting redundancy paths.
– Monitoring the status of all equipment.
– Patching and dumping any software.

Control is maintained by sending macro-commands via the onboard computer to the Instrument Control Unit (ICU).

Instrument performance

The ASAR instrument has several operating modes, which can be grouped into four areas:
– support modes
– operational modes
– calibration modes
– test/health-check modes.

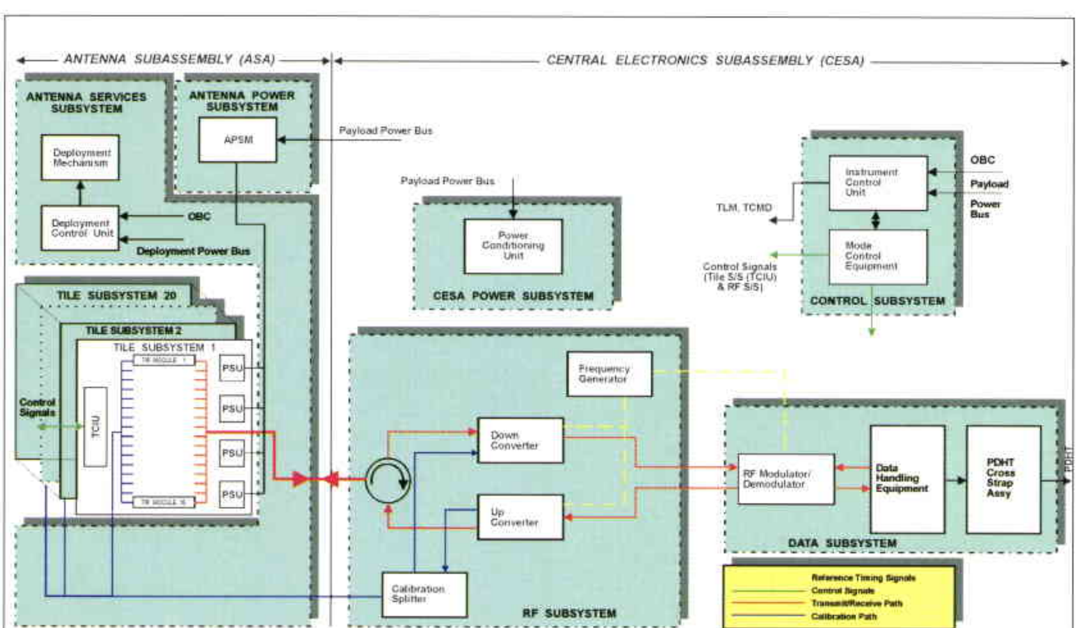
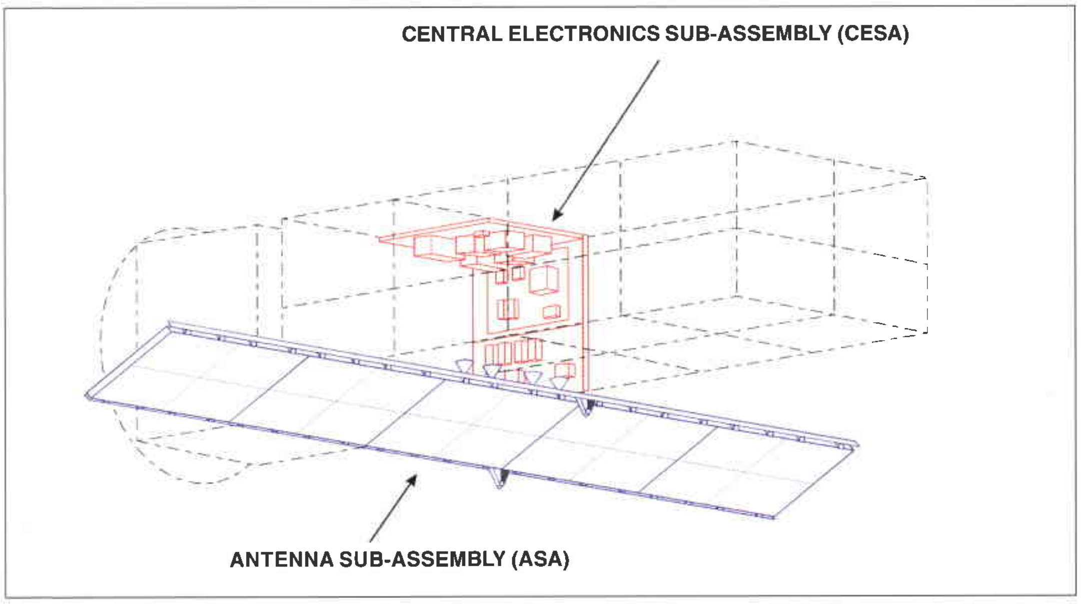


Figure 1. ASAR functional block diagram

Figure 2. The Envisat-1 ASAR mission configuration



Their various roles are summarised in Table 1.

The operational modes can themselves be divided into three different categories:

- high-spatial-resolution imaging modes
- low-spatial-resolution imaging modes
- wave mode.

High-spatial-resolution imaging modes
In these two modes – the so-called 'Image Mode' and 'Alternating Polarisation Mode' – the ASAR operates as an imaging radar with high spatial resolution (typically a few tens of metres), and relatively narrow swaths (up to 120 km). The radar geometry when operating in this manner is shown in Figure 3.

Table 1. ASAR operating modes

Support modes	
Off	Instrument electrically disconnected from the platform
Standby	Instrument communications active and capable of receiving commands and transmitting telemetry on demand. The internal monitoring system is active
Heater	Ovens of all units requiring temperature stabilisation are active and stable
Pre-operation	All units are active, but no transmissions are occurring
Operation modes	
Wide swath	This mode operates with wide swath and reduced spatial resolution
Image	High resolution, selectable swath position
Wave	Sampled imaging mode, low data rate
Global monitoring	Wide swath, low spatial resolution, low data rate
Alternating polarisation	Interleaved vertically and horizontally polarised (VV and HH) imaging at high resolution, selectable swath position
Calibration modes	
External calibration	External characterisation to ground receivers
Test/Health-check modes	
Module stepping	Individual health check on each T/R module
Test	On-ground testing facility

The Image Mode provides continuous coverage over a single swath nominally 100 km wide. The swath can be selected anywhere within a 500 km region (incidence angle range 15–45°). For nominal operation, seven swaths (IS1 to IS7) are defined over this region (Fig. 4). The imaging is performed by transmitting a continuous series of pulses and acquiring the required echo information after the appropriate return trip delay.

The transition to Image Mode is made automatically following the appropriate macro-command. Before the actual measurement of data is initiated, a period of stabilisation, noise measurement and internal calibration is performed. Echo measurement then starts, during which the initial calibration is updated on a regular basis. Image Mode operation continues uninterrupted until the receipt of a another macro-commmand to switch to another mode.

The Alternating Polarisation Mode provides vertically and horizontally polarised imaging of the same scene by interleaving looks with each polarisation along track within the synthetic aperture. The echo measurement is made within repetition cycles containing two bursts of transmissions on each of the polarisations. The sequence is only interrupted when the internal calibration requires updating (as for the Image Mode).

Low-spatial-resolution imaging modes
These are the 'Wide Swath Mode' and 'Global Monitoring Mode', in which the ASAR operates as an imaging radar with low spatial resolution (100 m to 1 km) and

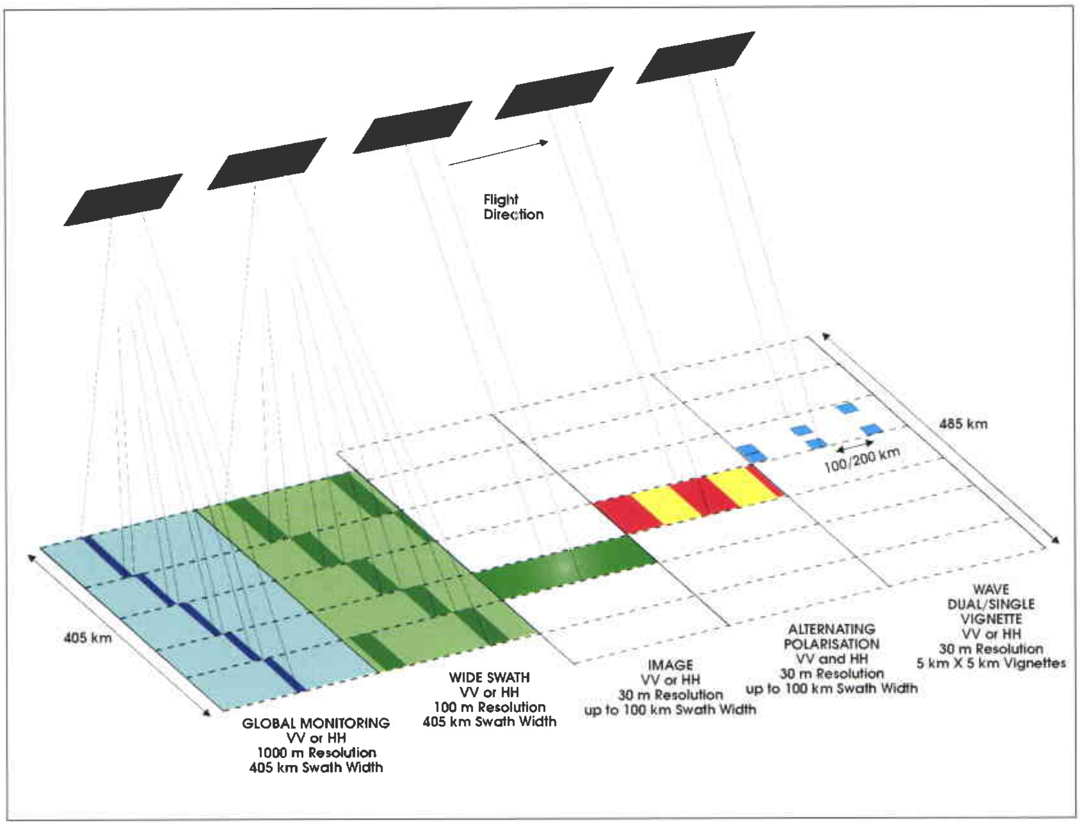


Figure 3. ASAR operating modes

relatively wide swath (more than 400 km). To obtain global coverage for the Global Monitoring Mode, the data is stored onboard the satellite and transferred to ground when it passes over a ground station.

The Wide Swath Mode provides continuous coverage over a swath nominally 400 km wide, which is divided into five subswaths ranging from 60 to 100 km in width (Fig. 4). The ASAR transmits bursts of pulses to each of the subswaths in turn in such a way that a continuous along-track image is built up for each subswath.

During a transition to Wide Swath Mode, all the necessary data transfers and timing parameters are established. Stabilisation, noise measurement and internal calibration follow in a similar manner to the Image Mode, after which the echo measurement sequence itself commences. For each

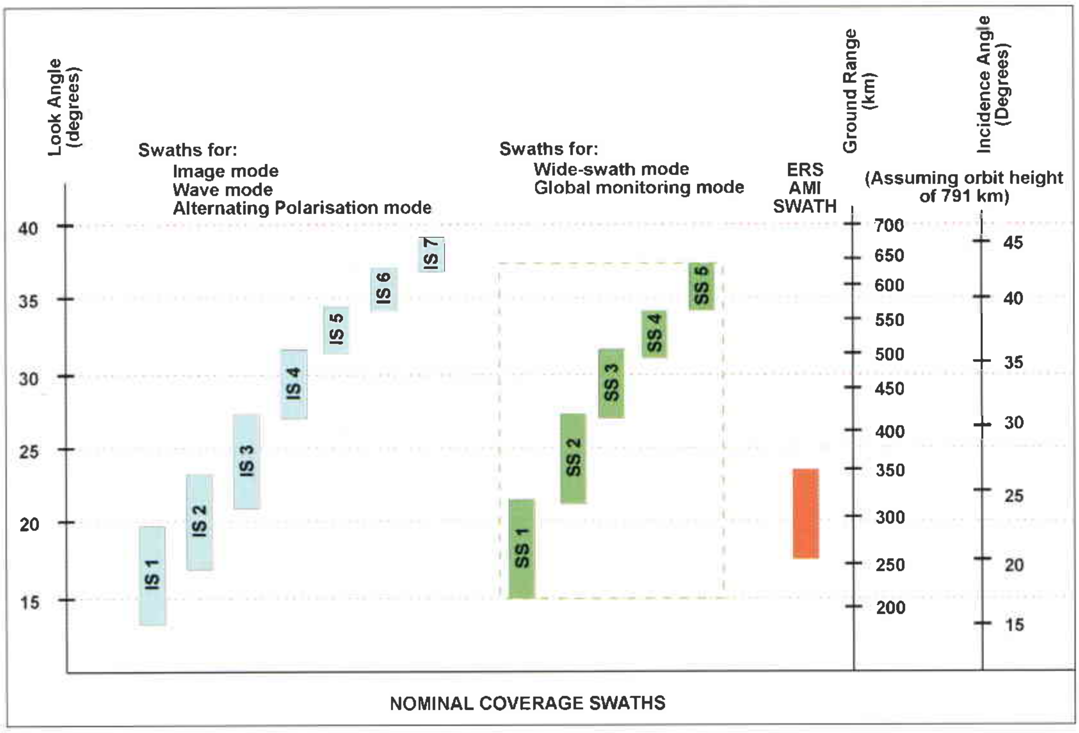


Figure 4. ASAR swath coverage

Figure 5. ASAR antenna element breadboard under test

subswath, there is a burst of transmissions followed by a short quiescent period whilst the echoes from the last transmit pulses are received. Transmissions then switch to the next subswath in the cycle. The updating of the internal calibration is performed at the end of each subswath transmission burst.

The Global Monitoring Mode provides continuous along-track sampling across a 400 km swath, again using a SAR scanning technique. This mode has a low data rate due to a slightly reduced along-track duty ratio and the use of digital filtering for reduction in the across-track direction. The same subswaths as defined for the Wide Swath Mode are used.

Wave mode

In the 'Wave Mode', the ASAR uses the facilities of the Image Mode to image small areas of the ocean surface, measuring the changes in radar backscatter from the surface due to wave action. The imaging is carried out to a high spatial resolution over one or two areas across a swath of approximately 5 km x 5 km at intervals of nominally 100 or 200 km in the along-track direction.

The transition to Wave Mode is identical to that for the Image Mode, including the initial calibration sequence. This is followed by a burst of transmissions covering the 5 km along-track vignette distance. A quiescent period is then used to transfer the data to the Payload Data Handling and Transmission System via the low-rate data interface. The total duration of the repetition cycle is the time taken to traverse the 100 or 200 km separation between vignettes. Noise and

Table 2. Predicted in-orbit performance of ASAR

	Operational modes					
Parameter	Unit	Image	Alt. polar	Wide swath	Global mon.	Wave
Polarisation	–	VV or HH	VV + HH	VV or HH	VV or HH	VV or HH
Spatial resolution	m	~30	~30	~100	~1000 m	~30
Radiometric resolution*	dB	1.8 to 3.0	2.9 to 4.7	2.6 to 3.0	1.6	1.6 to 2.5
Ambiguity ratios:*						
– Point target	dB	> 27	> 20 dB	> 23	> 25	> 27
– Distributed target	dB	7 to 21	8 to 23	7 to 25	9 to 26	7 to 22
Swath width	km	56 to 120	56 to 120	406	406	5 × 5
Incidence angle	deg	15–45	15–45			15–45
Localisation accuracy	km	< 0.35	< 0.35	< 0.35	< 0.35	< 0.35
DC power consumption	W	1200	1200			
Data rate (mean)	Mbit/s					
Radiometric accuracy	dB	< 1.4	< 1.4	< 1.4	< 1.3	< 1.7

* Swath dependent

calibration sequences are repeated at the start of each cycle.

The predicted in-orbit performances of the ASAR instrument in its various modes of operation are presented in Table 2. The instrument is still in the development stage and its final performance parameters will be established as part of the Preliminary Design Review, scheduled for early 1994.

Product processing
The images acquired by ASAR will be processed on the ground and distributed mainly from ESRIN in Frascati (I). The products will fall into four main categories:
- High-Resolution Images, generated within 24 h of sensing and normally distributed by non-electronic means, similar to the ERS-1 Precision Image (PRI).
- Fast-Delivery Products, delivered within 3 h of sensing via electronic links; this product will have a lower geometric resolution (approx. 100m pixels).
- Browse Products, delivered within 3 h, but with very low resolution, and used for Browse Catalogues.
- Wave Imagettes and Spectra, similar to the ERS-1 wave spectra, but with the ASAR enhancements.

Conclusion
In addition to achieving comparable performance to ERS-1 in the swath that coincides with the ERS-1 single fixed swath, the ASAR instrument will give Envisat-1:
- wider swath and incidence-angle coverage
- a second channel of information by means of the dual-polarisation capability
- variable spatial resolutions and data rates.

In addition, the ASAR can be tuned during its in-orbit lifetime to make optimum use of the power available. Satellite instrument designs are generally driven by end-of-life requirements, which often results in under-utilisation early in a mission. The ASAR's built-in flexibility will allow it to take advantage of beginning-of-life conditions. It will also enable operating modes other than the baseline modes that were identified in Table 1 to be explored during the Envisat-1 mission, thereby helping to define requirements and modes of operation for future SAR missions.

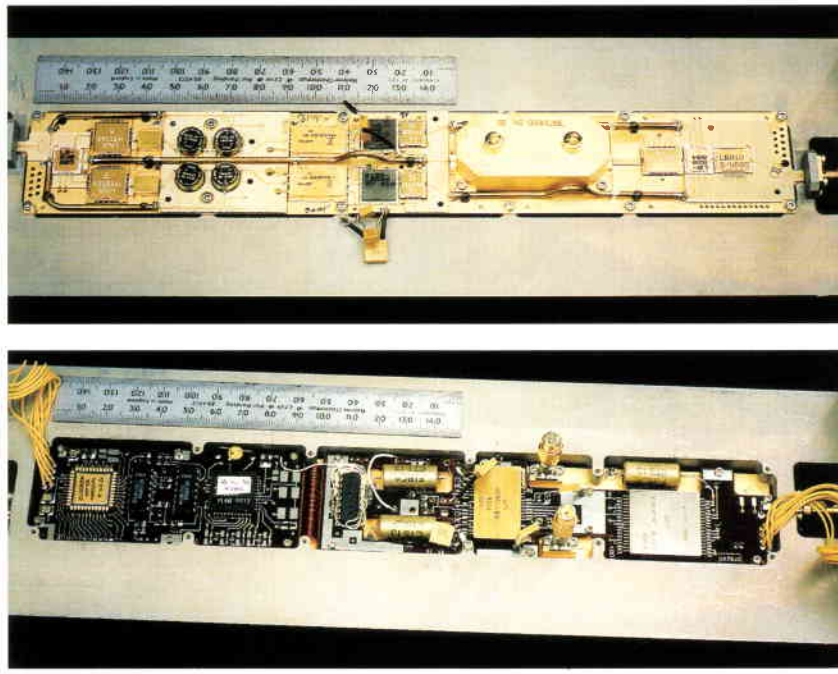


Figure 6. Elements of the ASAR's transmit/receive module electronics (photo courtesy of Matra Marconi Space/Alcatel)

Envisat's Global Ozone Monitoring by Occultations of Stars Instrument: GOMOS

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GOMOS is a medium-resolution spectrometer designed to measure the concentrations of, and monitor the trends in, ozone and and other atmospheric trace gases with very high accuracy. In addition, it can measure atmospheric turbulences, which are of interest for understanding the vertical exchange of energy between the lower and upper layers of the Earth's atmosphere. GOMOS offers global coverage in a broad spectral range, extending from the ultraviolet to the near-infrared, with emphasis on the polar regions, where the ozone problem is particularly pronounced.

GOMOS's role

Since the first signs of ozone depletion over the Antarctic were registered between 1979 and 1987, we have seen an alarming 45% reduction in ozone levels, which is commonly referred to as the 'ozone hole'. This has raised serious concerns that the Earth's protective ozone shield against ultraviolet radiation may be thinning rapidly, endangering the health of life on our planet. The scientific community therefore deems it vital to measure the ozone distribution and its trends accurately, globally and continuously in order that we may come to understand the mechanisms of ozone formation and destruction.

The GOMOS instrument to be carried on-board Envisat-1 was proposed jointly in 1989 by scientists from six European countries as a tool that would provide global ozone mapping and trend monitoring with unprecedented accuracy (to within 0.1% per year). Similar to the Stratospheric Aerosol and Gas Experiment (SAGE) flown previously, GOMOS uses an occultation technique. However, while SAGE used the Sun as the irradiance source, GOMOS will use the stars to give a much better geographical coverage and altitude resolution.

Using an occultation technique has benefits in terms of instrument calibration, as this method is largely self-calibrating, and long-term instrument drifts do not affect such differential-type measurements. The use of stars, which are effectively point sources, also has the advantage of providing very good altitude accuracy.

GOMOS will register the seasonal and long-term trends, and will also measure NO_2, NO_3, H_2O, OClO, BrO, ClO, aerosols and vertical temperature distributions, parameters of primary importance for understanding the ozone balance and its driver mechanisms.

Figure 1 shows the target species and the altitude ranges to be covered, while Figure 2 indicates the relations between the target species and the spectral ranges of observation. The primary mission objective is to be achieved by monitoring stellar light sources (stars with visual magnitudes between −1 and 3) setting through the Earth's atmosphere.

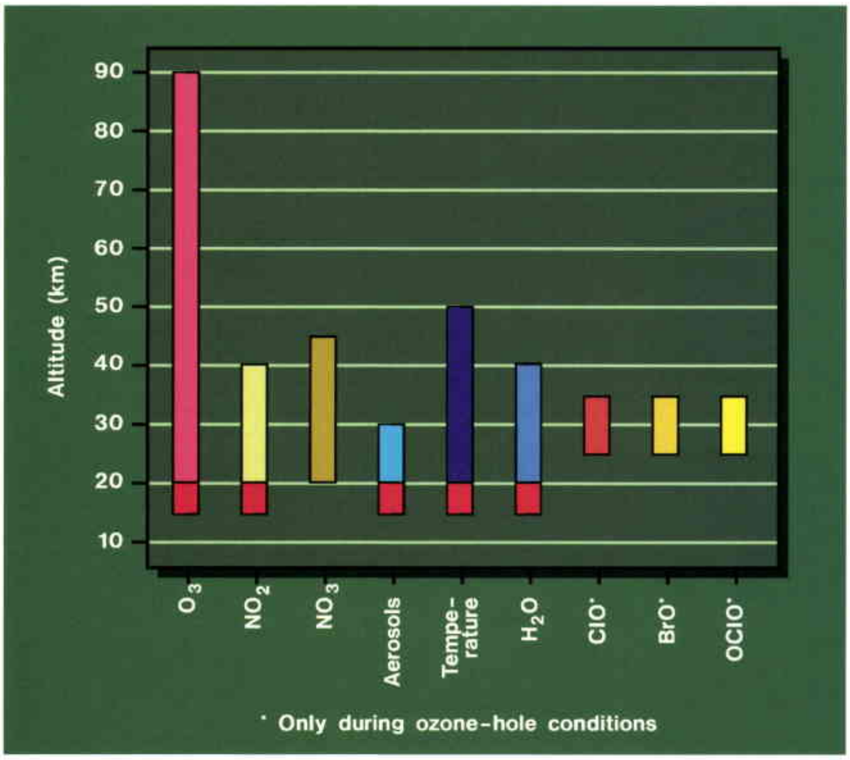


Figure 1. Target species as a function of altitude covered

High relative accuracy ('precision') and high measurement repeatability are of paramount importance. For ozone concentrations, target values of better than 3% between 20 and 70 km, and better than 10% between 70 and 90 km, will be possible for single occultation measurements. For a four-year mission duration, detectable trends in 20° latitude bands will be of the order of 0.1% per year.

The aim in monitoring atmospheric turbulence, as a secondary mission objective, is to determine the eddy diffusion coefficient by modelling, using measured temperature and density fluctuations in the atmosphere. This parameter provides insight into the vertical exchange of energy between the lower and upper layers of the Earth's atmosphere.

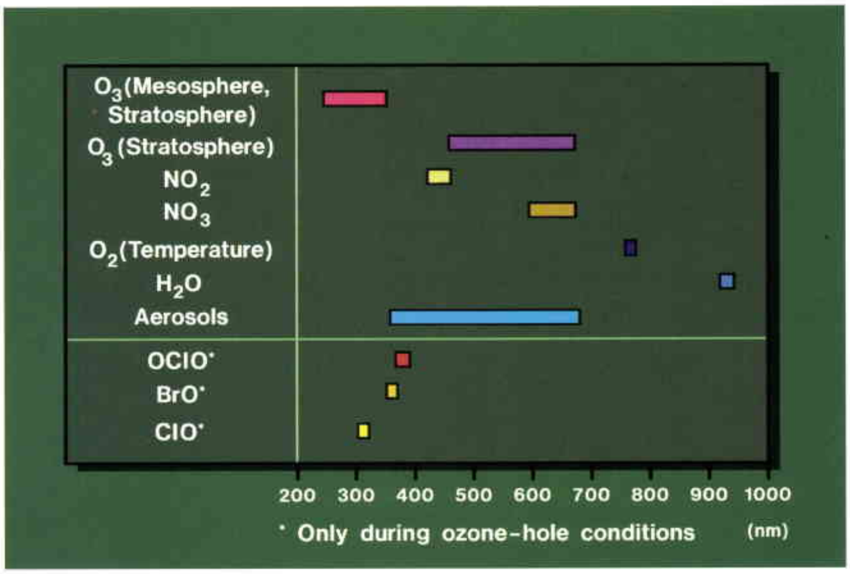


Figure 2. Relation between target species and observational wavelength

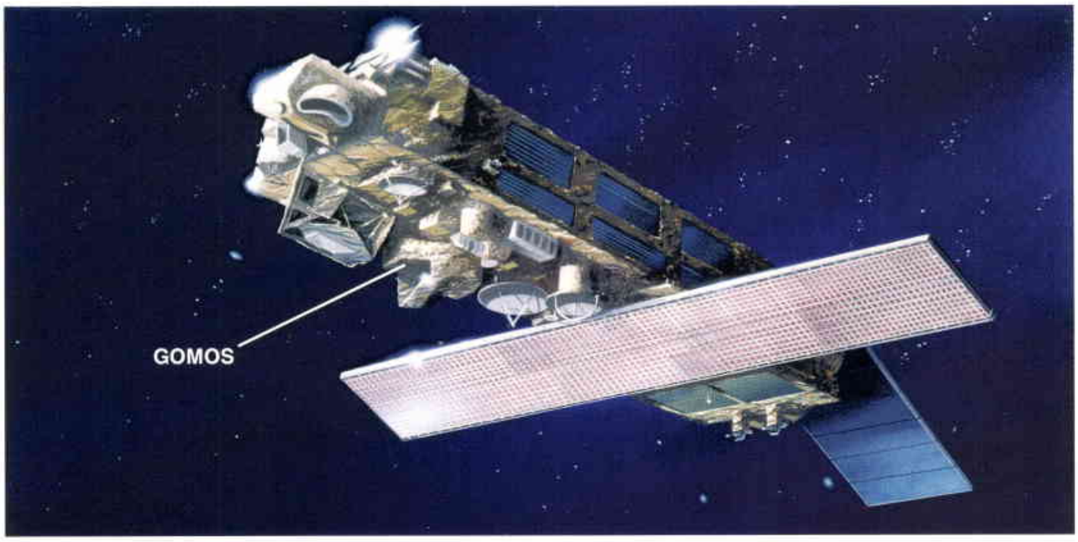
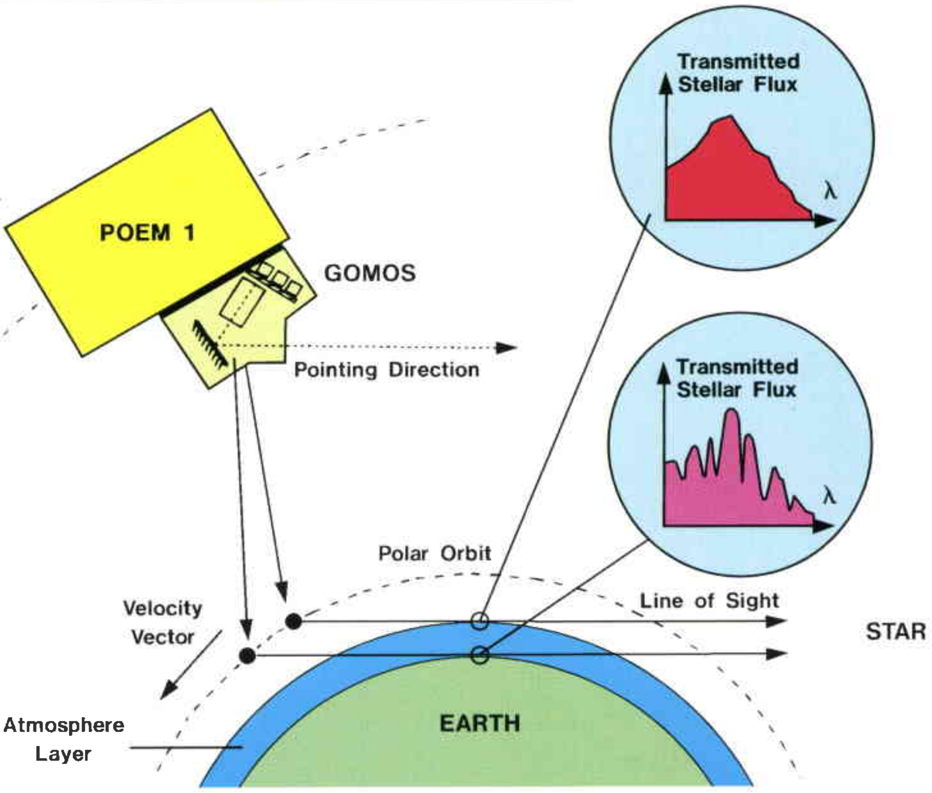


Figure 3. Accommodation of the GOMOS instrument on Envisat-1

Figure 4. GOMOS's measurement principle

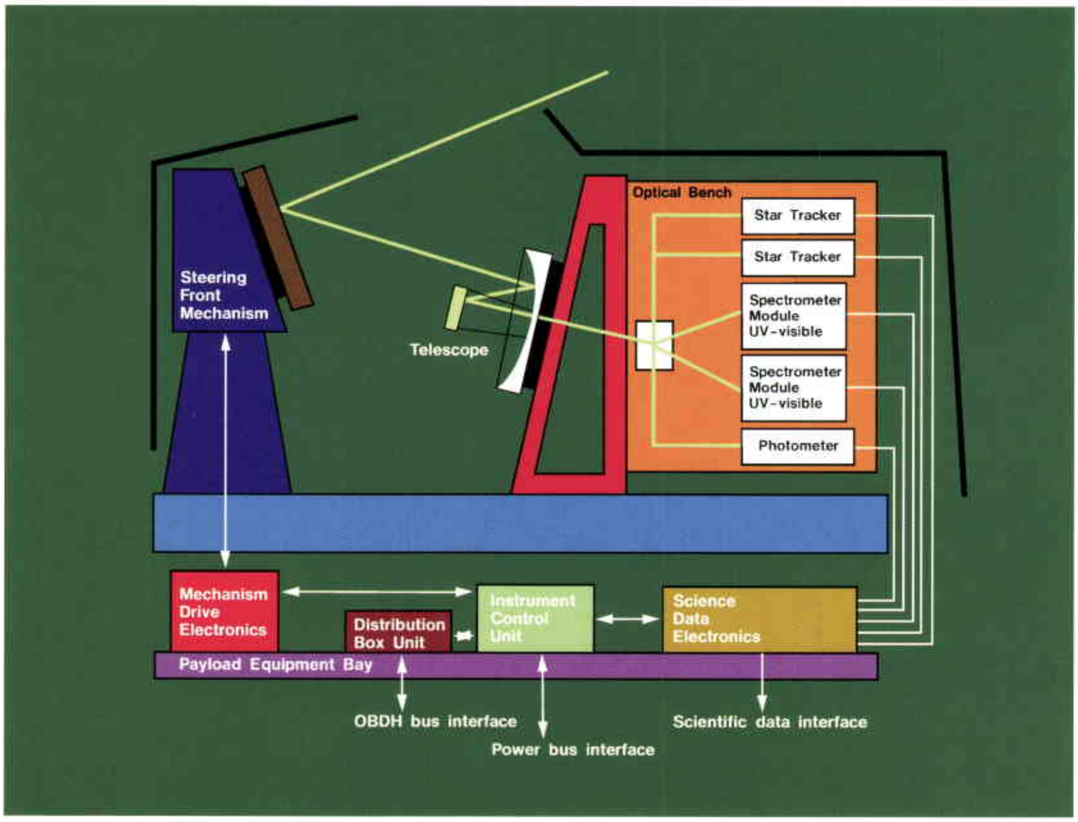
The GOMOS instrument

The GOMOS instrument and its accommodation onboard Envisat-1 is shown in Figure 3. The instrument line of sight can be successively oriented towards preselected stars and maintained on each whilst the star is setting behind the Earth's atmosphere observed at the horizon (Fig. 4). During this 'occultation' observation, the ultraviolet, visible and near-infrared spectra of the star are continuously recorded. As the star 'sets' through the atmosphere, its spectrum becomes more and more attenuated by the absorptions of the various atmospheric species, each of which is characterised by a well-defined spectral signature.



Back on the ground, these attenuated spectra recorded by GOMOS can be compared with the unattenuated one measured, a few seconds earlier, outside the atmosphere, so allowing the absorption spectra to be derived very accurately. This self-calibrating method is protected from sensitivity drifts and is thus capable of

Figure 5. GOMOS functional block diagram



fulfilling the delicate objective of reliably detecting small trends in ozone and other gas distributions.

Use of the star occultation method rather than Sun-based measurement techniques offers several major advantages, including:

- better altitude resolution
- better global coverage
- both night- and day-side measurement capabilities.

Instrument performance

The GOMOS instrument (Fig. 5) is based on a single telescope feeding, via an optical beam dispatcher, the ultraviolet–visible and the near-infrared spectrometers, two photometers (monitoring the input signal scintillation) and two (redundant) star trackers (Fig. 6). All sensors and their associated front-end electronics are mounted on a thermally controlled CFRP optical bench.

The 300 mm x 400 mm two-stage Steering Front Mechanism (SFM) has an angular steering range of 100° in azimuth and 8° in elevation, and a pointing accuracy of some 10 microradians at a bandwidth of 5 Hz.

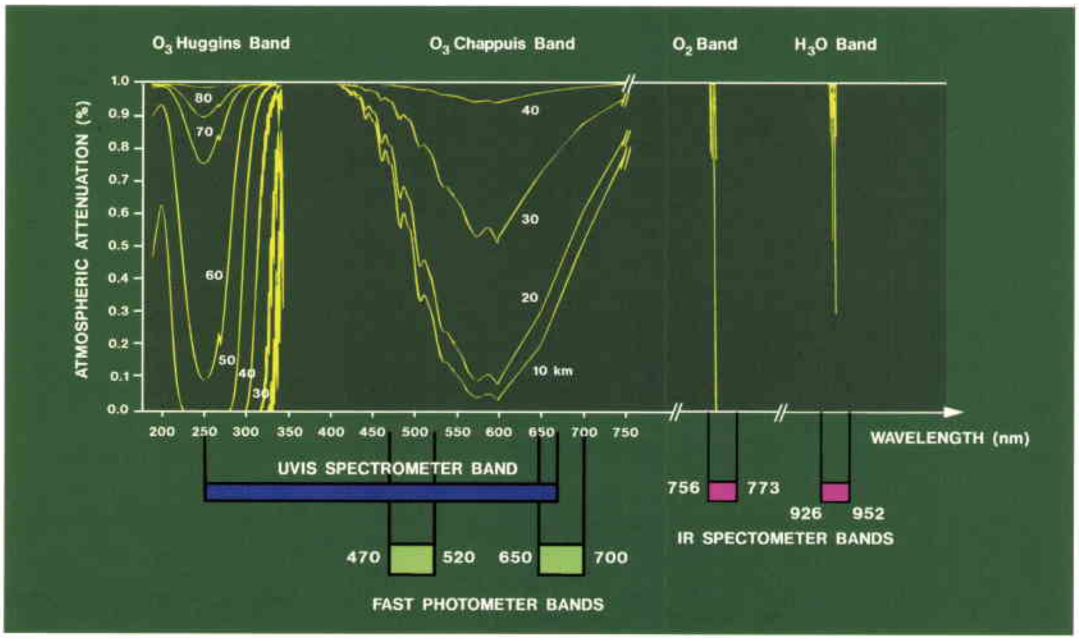


Figure 6. GOMOS spectral-band partition

The SFM relies on a combination of linear motors and flexible joints for its operation. The accurate tracking function is performed via a digital closed control loop using star-tracker information read at 100 Hz. There is a cover around both the optical assembly and the SFM to provide adequate stray-light and thermal shielding (Fig. 7).

The instrument's signal-conditioning and control electronics consists of several boxes mounted inside Envisat's Payload Equipment Bay.

The performance parameters of the GOMOS instrument, which weighs less than 150 kg, has a power consumption of less than 180 W, and will deliver scientific data at a rate of 220 kbit/s, are summarised in Table 1.

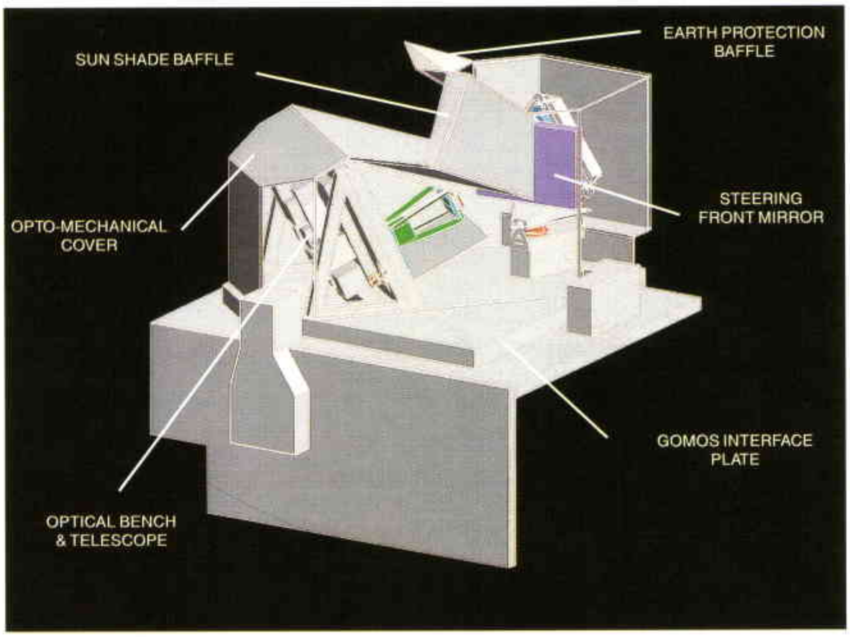


Figure 7. Structure of the GOMOS instrument

Table 1. GOMOS instrument performance characteristics

	UV-visible spectrometer	IR1 spectrometer	IR2 spectrometer	Photometer
Spectral range (nm)	250 – 675	756 – 773	926 – 952	650 – 700 & 470 – 520
Resolution (nm)	0.9	0.12	0.16	N/A
Signal-to-noise ratio	> 12	> 6	> 3	> 15
Linearity	1%	1%	1%	N/A
Stability	1%	1%	1%	N/A

Worst signal-to-noise conditions occur when tracking the faintest star of the catalogue

The occultation-mode operation of GOMOS involves pointing the instrument towards pre-selected stars, acquiring and then tracking them with high accuracy. To help meet the stringent measurement requirements, the instrument has three additional calibration modes:
- a linearity monitoring mode, allowing one to calibrate for possible non-linearity of the sensor chains within the large dynamic range (some 40 dB signal range)
- a spatial-spread monitoring mode, allowing one to optimise the position of the CCD read-out regions with respect to that of the stellar spectrum, and
- a uniformity monitoring mode, which allows measurement of the sensitivity difference between the various CCD pixels of a spectral sampling interval; such pixel-to-pixel sensitivity differences, which cannot be corrected for on the ground, would otherwise reduce the measurement accuracy.

Product processing

The stellar spectra are transmitted to the ground, where the algorithms for data processing and product extraction will be applied for the retrieval of ozone and other trace-gas profiles and trends.

Conclusion

The GOMOS instrument to be carried by Envisat-1 is a very accurate atmospheric monitoring device which will exploit the powerful star-occultation measuring principle for the first time. In synergy with the other Envisat-1 payload instruments, GOMOS promises to contribute significantly to environmental monitoring and to our understanding of the mechanisms governing atmospheric chemistry.

The GOMOS instrument is being developed in conjunction with Matra Marconi Space (F), the industrial Prime Contractor.

Acknowledgement

We would like to thank the members of the GOMOS Science Advisory Group for their support during the instrument definition process, and in particular C. Readings (ESA), J. Bertaux (Service d'Aeronomie, F), G. Leppelmeier (Finnish Meteorological Institute) and N. Papineau (CNES, F).

Envisat's Medium-Resolution Imaging Spectrometer: MERIS

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The Medium-Resolution Imaging Spectrometer (MERIS) carried by Envisat-1 will provide an essential contribution to ocean-colour measurements and hence to our understanding of marine phenomena and processes. As secondary mission goals, MERIS will contribute to atmospheric investigations of clouds and aerosols. It will also provide data on the land surface, including global-scale monitoring of vegetation, its distribution, extent and condition.

MERIS's role

It is believed that the ocean carries one third to one half of the heat transferred from the Earth's equator to its poles. In fact, it is the existence of this flux that keeps the mid-latitude regions of the Earth habitable. The ocean is the major sink for the constantly increasing human production of carbon dioxide and other 'greenhouse gases'. Analyses of cores from the ocean floor strongly suggest that during the distant past, when the Earth's climate was very different, the ocean circulation was also radically different.

Therefore, more information is urgently needed on oceanic circulation and changes and the oceanic carbon cycle. Present models of the ocean are inaccurate owing both to uncertainties concerning the governing physics, chemistry, and biology, and due to an inadequate ability to describe the instantaneous state of the system. Envisat-1 will offer the continuous, global observations of the oceans required to provide data sets for improved ocean modelling.

The remote-sensing measurement that has attracted the greatest interest within the International Joint Global Ocean Flux Study is the estimation of basin and global-scale variability in the concentration of chlorophyll in the upper ocean. Images of the global distribution of pigments, derived from the US Coastal-Zone Colour Scanner (CZCS), have revolutionised the way in which biological oceanographers perceive the oceans.

The ocean algae reservoir is poorly understood. In particular, the amounts of carbon converted from dissolved inorganic forms into organic compounds that are added to oceanic biomass is unknown. Progress in understanding the oceanic carbon cycle and in quantifying the fluxes can be made with the help of satellite ocean-colour sensors, which provide both repetitive coverage and synoptic viewing.

MERIS will provide international users with a sensor specifically designed for the remote assessment of marine phenomena and processes. It will also contribute to atmospheric investigations into the global coverage of clouds and data on cloud-top heights, as well as the type and optical thickness of atmopheric aerosols.

For land studies, the number of cover types to be discriminated is very large; consequently, it is inevitable that spectral separation of some classes is difficult. Narrow-band sensing through MERIS will contribute to the definition of band characteristics for use in land observation.

In addition to these scientific applications, MERIS will make a contribution, in combination with other measurement techniques, to:

- Measurements of coastal erosion, transport and deposition used for the design of coastal defences; these measurements are of great interest for the definition of computer models.
- Measurements of sediment in coastal zones; these could be used in assessing the need for dredging.
- Measurements of pollution-derived aerosols over industrial zones, airports and cities; these are of interest to determine the sources of and temporal trends in pollution.

The MERIS instrument

MERIS is a programmable, high-spectral-resolution, imaging spectrometer operating in the solar reflective spectral range. Up to fifteen spectral bands can be selected by ground command, each of which has a programmable width and a programmable location in the 400–1050 nm spectral range.

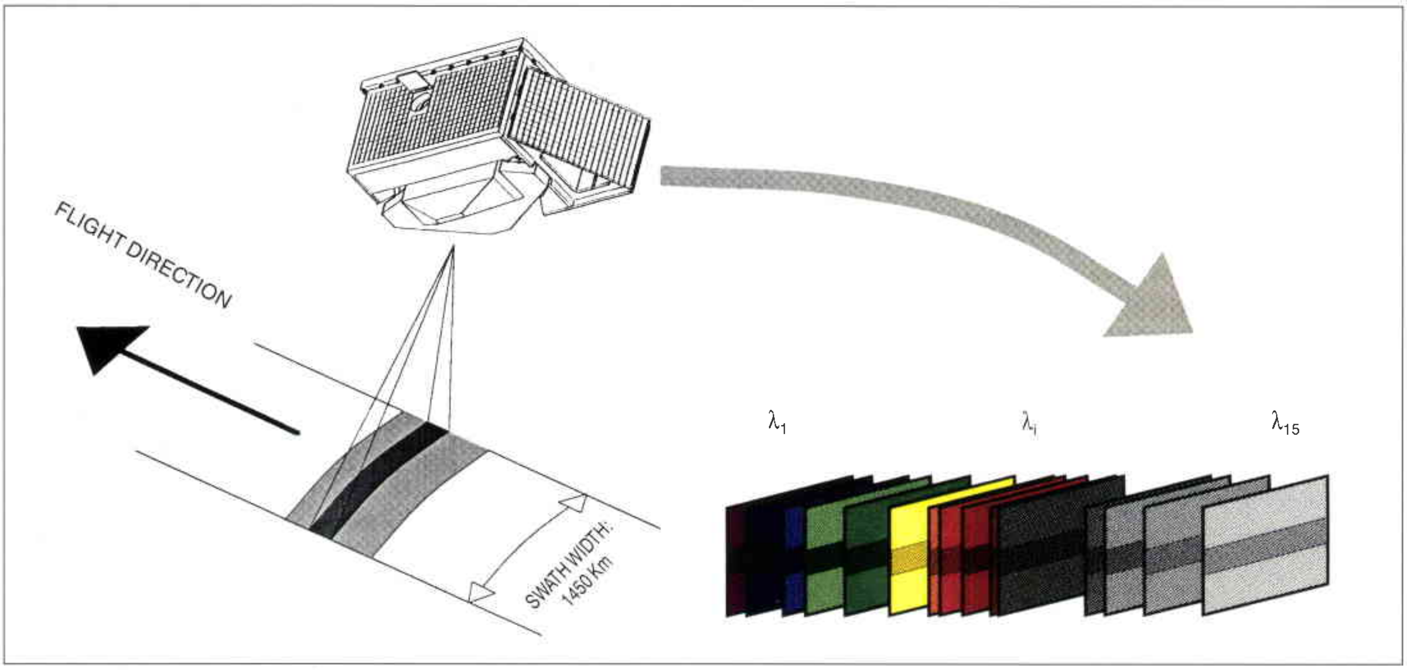
The instrument scans the Earth's surface by the so-called 'push-broom' method (Fig. 1). Radiation-sensitive arrays (CCDs) provide spatial sampling in the across-track direction, while the satellite's motion provides scanning in the along-track direction.

MERIS is designed so that it can acquire data over the Earth whenever illumination conditions are suitable. The instrument's 82° field of view around nadir covers a swath width of 1450 km. This wide field of view is shared between six identical optical modules arranged in a fan-like configuration (Fig. 2). The deflecting mirror switches between an Earth-viewing position and a view of the onboard calibration source. In the calibration mode, correction parameters such as offset and gain are generated, which are then used to correct the recorded spectra. This correction can be carried out either on-board or on the ground.

The Earth is imaged with a spatial resolution of 300 m (at nadir). This resolution is reduced to 1200 m by the on-board combination of four adjacent samples across track over four successive lines. This reduction also reduces the data rate to what can be recorded with the on-board tape recorders. Full-resolution data (300 m) will be transmitted over coastal zones and land surfaces where the communications capability exists. This includes Europe, which will be covered by Data-Relay Satellites. Reduced-resolution data (1200 m) will be recorded continuously on-board and dumped at least once per orbit.

The scene is imaged simultaneously across the entire spectral range, through a dispersing system, onto the CCD array. Signals read out from the CCD pass through several processing steps in order to achieve the required image quality. These CCD processing tasks include dumping of spectral information from unwanted bands, and spectral integration to obtain the required bandwidth. On-board analogue electronics perform pre-amplification of the signal and correlated double sampling and gain

Figure 1. The MERIS 'pushbroom' mode



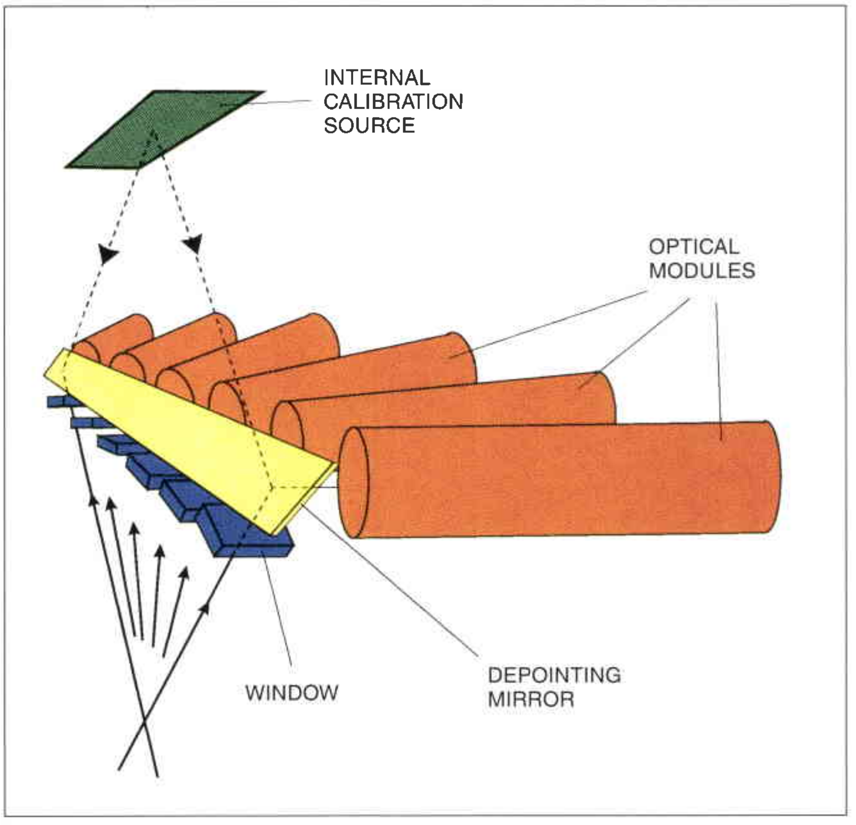


Figure 2. The arrangement of MERIS's optical modules and the deflecting mirror

adjustment before digitisation. The on-board digital electronics has three major functions: it completes the spectral integration, performs offset and gain corrections, and creates the reduced-resolution data when required.

The engineering requirements on the instrument, which have been derived from the Envisat-1 mission requirements, are as follows:

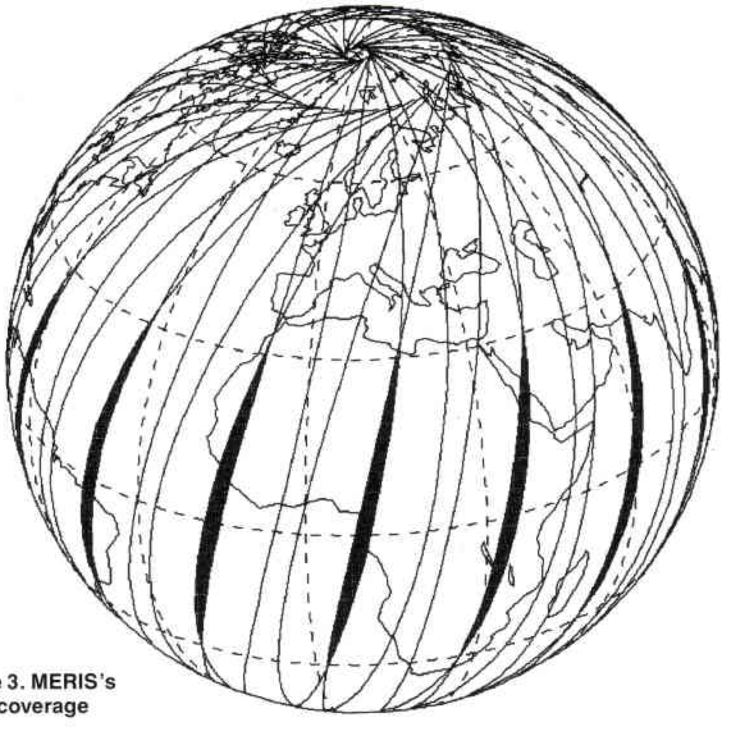


Figure 3. MERIS's Earth coverage

Spectral range:	400–1050 nm
Spectral resolution:	2.5 nm
Band transmission capability:	Up to 15 spectral bands, programmable in position and width
Band-to-band registration:	Less than 0.1 pixel
Band-centre knowledge accuracy:	Less than 1 nm
Polarisation sensitivity:	Less than 1%
Radiometric accuracy:	Less than 2 % of detected signal, relative to Sun
Band-to-band accuracy:	Less than 0.1 %
Dynamic range:	Up to albedo 1.0
Field of view:	±41°
Spatial resolution:	300 m at nadir

Instrument performance

Earth coverage

MERIS's 82° field of view allows global coverage to be provided in two to three days, as required by oceanographic, land and atmopsheric investigations. Figure 3 shows the MERIS Earth coverage over two consecutive operating days.

Because MERIS operates in the visible and near-infrared, the radiometric quality of the data acquired will depend on the illumination of the Earth. The solar zenith angle varies with the day in the year, the angular position in the instrument's field of view, and the nodal crossing time of the Envisat-1 Sun-synchronous orbit. A solar zenith angle of less than 80° is needed for effective recovery of geophysical data from MERIS.

The nodal crossing time changes slightly during the year due to the elliptical trajectory of the Earth around the Sun. In Figure 4, the contours corresponding to solar zenith angles of 30, 40, 50, 60, 70 and 80° are given for every day in the year and at the subsatellite point (SSP). The black dot indicates the position of the minimum solar zenith angle (23.6°). The nodal crossing time has been set to 09.55 a.m. on 1 January, such that its variations are symmetrically distributed around the nominal value (10.00 a.m.).

Ocean sensing

When observing the ocean surface (which is a primary goal for MERIS), at least 90% of the photons received will originate from scattering by air molecules and/or aerosols

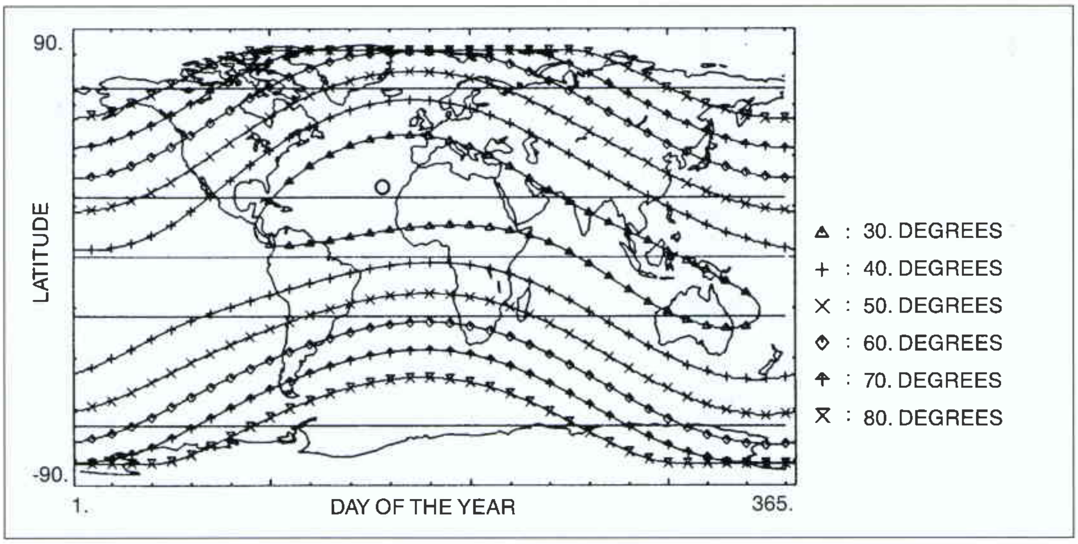


Figure 4. MERIS subsatellite-point coverage as a function of solar zenith angle

or from reflection at the ocean's surface. This light has never penetrated the surface. Even under the most favourable observation conditions (clear atmosphere and vertical Sun illumination), the 'marine radiance' originating from photons back-scattered from the ocean after having penetrated the surface water, and therefore carrying information about the water itself, represent only about 10% of the total received signal.

Figure 5 shows the total radiance at satellite level and the radiance contribution of the marine signal, expressed as a percentage of the total signal. The figure is for standard conditions, visibility of 23 km, and a chlorophyll pigment concentration of 0.3 mg/m^3 at the 445 nm wavelength used for cholorphyll detection.

Atmospheric corrections

Much experience has been acquired in atmospheric correction for ocean-colour products since the launch of the Coastal-Zone Colour Scanner (CZCS) instrument on-board the Nimbus-7 satellite in 1978. This allows the new generation of ocean-colour sensors, including MERIS, to be well-prepared.

The limited number of channels and the relatively poor radiometric sensitivity of CZCS led to the development of correction schemes designed partly to remedy this weakness. MERIS, however, with its improved spectral coverage and radiometric sensitivity will render such correction schemes unnecessary. MERIS's increased radiometric sensitivity does mean, however, that some other phenomena, neglected in the past because their effect on the recorded signal was below the noise level, must now be considered.

The first step in terms of atmospheric correction is to compute the Rayleigh scattering for

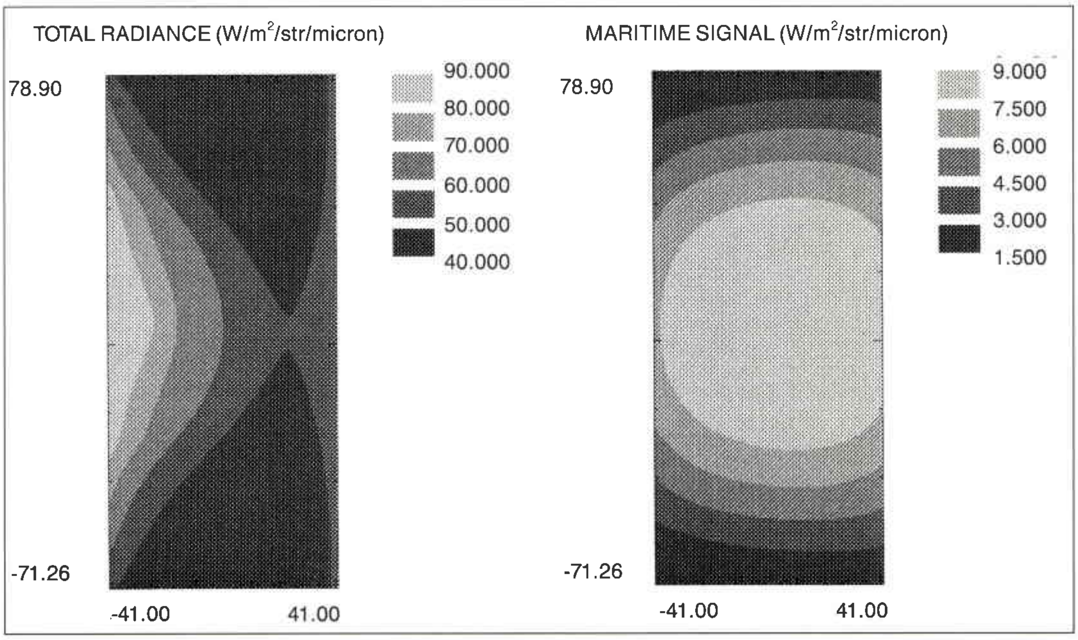


Figure 5. Total radiance at sensor level and the marine signal contribution

any wavelength, which depends upon the atmospheric pressure and upon the viewing configuration. In a second correction step, the aerosol contribution is determined. For MERIS, the variation of the aerosol contribution with wavelength will be estimated without any assumptions regarding marine reflectance, which is non-existent above 700 nm. The correction of the aerosol effect relies upon an extrapolation from the near-infrared channels to the visible.

For past ocean-colour data, the aerosol contribution was estimated using only a single scattering approximation. In the future MERIS data-correction scheme, multi-scattering and the coupling between the aerosol and Rayleigh scattering can be accurately computed. This will be one of the most significant improvements compared to the previous correction procedures. Algorithms for future ocean-colour processing, as well as alternative procedures based on extensive Monte-Carlo simulations of the whole ocean/atmosphere system, are under study at the Laboratoire de Physique et Chimie Marines in Villefranche sur Mer (F).

Chlorophyll pigment concentrations

As mentioned above, some new aspects of atmosphere/ocean optics will have to be taken into account when processing MERIS data to retrieve the ocean pigment concentrations, since their effects on the measured signal should be detectable as a result of MERIS's high radiometric sensitivity.

Retrieval of pigment concentration is achieved by using the 'water-leaving radiance'. Of importance in this extraction is the ratio between the observed light that has been totally reflected by the water surface, and the light that has entered the water and has re-emerged. This so-called 'Q-factor' depends upon the geometrical viewing configuration of the observer, the scene and the Sun.

Figure 6 shows the Q-factor as a function of latitude (ordinates) and viewing angle (abscissae) in the instrument field of view. These values are derived from simulated geometrical and Sun-illumination conditions encountered by MERIS. Exact calculation of the Q-factor will require an iterative procedure, beginning with an estimated Q-value, and testing the consistency of this with an estimated chlorophyll pigment concentratiion and adjusting the estimates where appropriate.

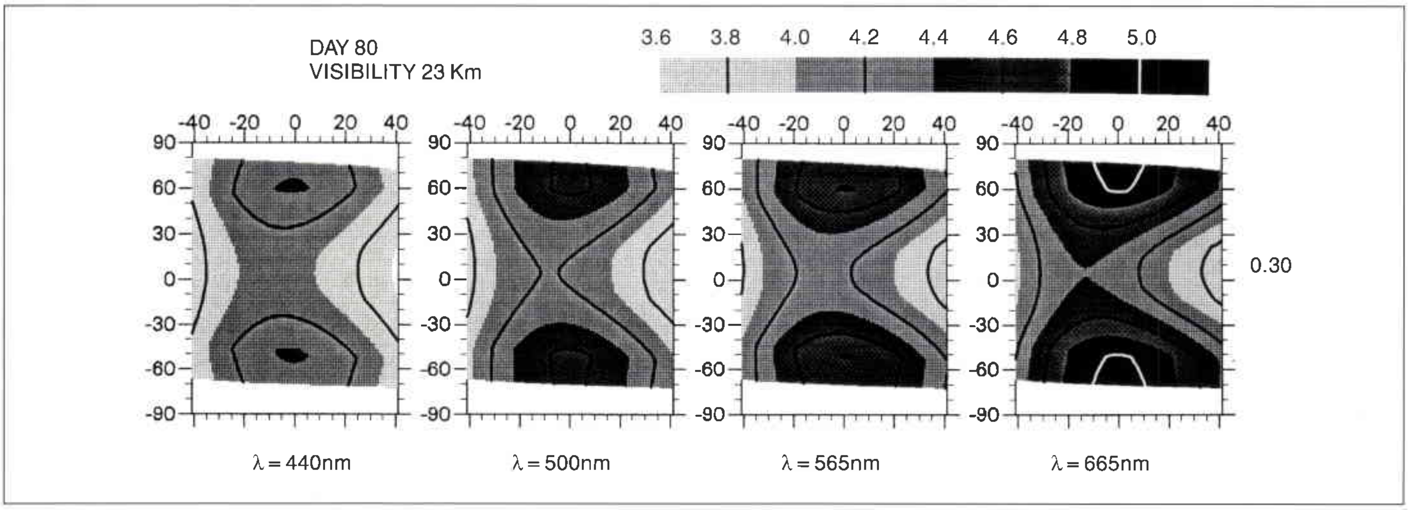
The computations summarised in Figure 6 assumed a flat ocean. Recent work has examined the effect of a rough sea on the total signal, and concluded that sea state should also be taken into account. This can, however, be done simply by using wind speed as the single variable.

Coastal-water constituents

Coastal waters are the most productive ocean regions. These marine ecosystems are subject to man-made biochemical pollution from rivers and the atmosphere. Large amounts of agricultural and industrial pollutants and sewage are also discharged into them. This pollution leads to enhanced marine productivity and eventually to entrophication.

The similarity of the spectral scattering and absorption coefficients for all optically active water-borne substances means that simple detection techniques, relying for example on colour ratios, cannot be used. More advanced interpretation methods are needed for their detection and separation. Eigen- and factor-analysis have been applied to measured and simulated multispectral radiances to demonstrate that the most

Figure 6. Values of 'Q-factor' over the MERIS swath width



important water-borne substances are in fact detectable by MERIS.

The inverse modelling technique tackles the detection and separation of the different substances from multi-channel measurements. The method of Doerffer & Fischer is based on a simple two-stream radiative-transfer model, which is adjusted to the results of a complete radiative-transfer model of the combined atmosphere/ocean system. They applied the technique successfully to CZCS measurements, and detected firstly the pigment and the suspended matter concentrations, as well as the yellow-substance absorption, in the North Sea.

Atmospheric parameters

The radiance balance of the Earth/atmosphere system is altered significantly by aerosols, clouds and water vapour. A global inventory of aerosol and cloud properties as well as of atmospheric water vapour over an extended period is a pre-requisite to our achieving a deeper understanding of climate. Climate studies as well as weather forecasts will benefit from evaluation of these quantities. MERIS will be able to detect these atmospheric properties with an accuracy never before realised with satellite observations.

The impact of aerosols on the radiation budget is both direct, through scattering and absorption, and indirect, through the modification of cloud properties. The magnitude of the influence of aerosols on climate is difficult to assess, largely because aerosols vary drastically in size, distribution, shape and chemical composition. MERIS will provide data to support an evaluation of aerosol properties, such as 'path radiance', type and concentration. The retrieval methods are basically adopted from the atmospheric-correction algorithm described previously for marine signal retrieval.

Two of the most important cloud properties with respect to global climate change are cloud-top height and cloud optical thickness. The estimation of cloud top height from reflected solar radiation is based on radiance measurements within and outside the oxygen-absorption band centred at 761 nm. Three of MERIS's proposed channels, two of which are within this absorption band, are selected to account for the photon penetration in the cloud-top evaluation process. The result of a principal-components analysis based on 160 000 spectral measurements above clouds confirms that these three channels are sufficient to retrieve cloud-top height and cloud optical thickness from multispectral measurements by means of inverse modelling techniques.

Water vapour is the most important atmospheric gas with respect to radiation budget, cloud amount, precipitation and evaporation rates. A detailed and long-term global view of the spatial and temporal distribution of the total atmospheric water-vapour content is therefore needed.

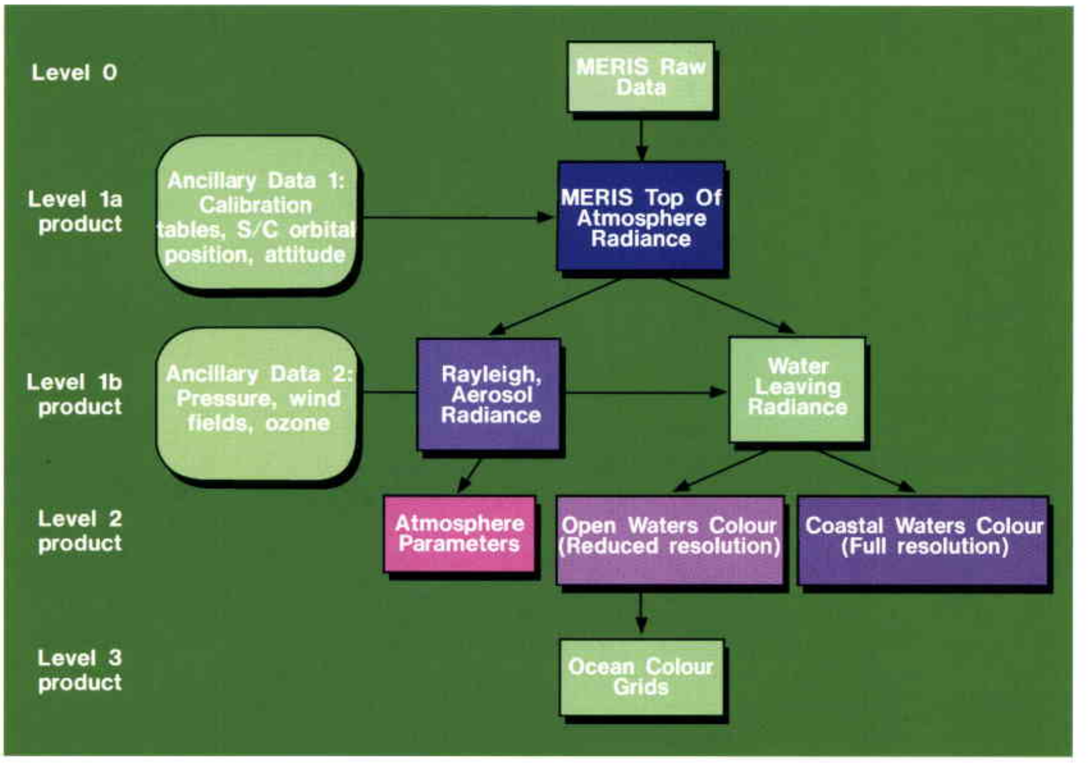


Figure 7. Schematic of the ocean-colour processing scheme for MERIS

The ratio of reflected radiances within the water-absorption band is used as an indicator for the total amount of atmospheric water vapour. Although these radiances depend strongly on the albedo of the surface and its wavelengths, as well as on the atmospheric aerosols, the accuracy of the total atmospheric water-vapour estimation is expected to be within 10% for measurements above water and land surfaces.

In cooperation with the University of Hamburg, the Free University of Berlin is developing a method of determining the total water-vapour content from MERIS measurements.

Product processing

One possible scheme for the end-to-end processing chain for MERIS ocean-colour products is shown schematically in Figure 7. This chain includes the product family described in the foregoing paragraphs. Its architecture takes into account the precedence and commonalities of the MERIS ocean-colour products family.

Radiometric calibration is performed for each incoming MERIS pixel using corrections for intra- and inter-module gain. The calibration coefficients are read from a calibration table generated at each calibration pass of MERIS (typically once per week). Identification of the central band wavelength and widths is performed by reading a wavelength calibration table, which is updated typically once per month.

Geometric correction takes into account the geometry of the instrument, distortions introduced on-board Envisat-1, and the orbit and attitude of the platform.

The end-to-end MERIS product chain generates atmospheric parameters and surface-leaving radiance products (land and ocean) from top-of-atmosphere radiance products. The generation of surface-leaving radiance products relies on the availability of additional atmospheric parameters, such as surface pressure, wind field and ozone column content (which will be available from other sensors).

Conclusion

The discipline of bio-optical oceanography, devoted to the assessment of ocean-surface optical properties and water constituents, leading to phytoplankton biomass and various pigment estimates, has developed dramatically in the past decade. The impact of these findings on our understanding of global climate is also becoming more and more evident. The marine component of the carbon cycle, in fact, plays an important role in shaping the climatic variability of the Earth, which is an essential element in the understanding of our environment.

The above analysis is based on the coordinated scientific and industrial work performed during the last four years on ocean-colour applications under ESA funding. Further work on two main issues is needed to define the MERIS instrument data processing and dissemination chains:

- The extremely large amount of data produced by MERIS will place heavy demands on the end-to-end processing chains, on the dissemination to users, on the archiving capacity, and on the archive retrieval system. Effective means are still being sought to deal with this issue.
- Many algorithms needed for MERIS need to evolve from their current experimental status to that of fully validated operational software. A coordinated algorithm development effort must continue. The development of support models and simulations and the associated operations software development, must take place in parallel with algorithm development.

MERIS will provide remotely sensed products offering continuity and some degree of comparability with current satellite sensors. In addition, it will provide novel experimental products that have been unavailable in the past. One such example would be a measure of the boundary position between chlorophyll absorption at red wavelengths and leaf scattering in the near-infrared to estimate both chlorophyll concentrations and vegetation condition.

Envisat's High-Resolution Limb Sounder: MIPAS

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MIPAS, the Michelson Interferometer for Passive Atmospheric Sounding, is a high-resolution Fourier-transform spectrometer designed to measure the concentration profiles of atmospheric constituents on a global scale. It will observe the atmospheric emissions from the Earth horizon (limb) throughout the mid-infrared region, which will allow the simultaneous measurement of more than 20 trace gases, including the complete family of nitrogen–oxygen compounds and several CFCs. MIPAS will provide global data coverage, including in particular the polar regions, where the stratospheric chemistry is currently exhibiting alarming changes.

MIPAS's role

In view of the observed changes in ozone concentration and of the greenhouse effect in the Earth's atmosphere, ESA initiated a study in the late eighties into the usefulness of various limb-sounding instruments. It identified Fourier-Transform Spectrometers in the Infra-Red (FTIRs) as especially suitable, due to their ability to detect wide spectral intervals with high spectral resolution. This allows them to detect many atmospheric trace species in the same air volume simultaneously. At the time of the study, such an FTIR had already been developed as a laboratory model and operated aboard a stratospheric balloon gondola by IMK Karlsruhe.

A modified version of this Michelson Interferometer for Passive Atmospheric Sounding, known as 'MIPAS', was proposed by the same group in response to a call for Announcement of Opportunity instruments for the Agency's Polar Orbiting Earth-observation Mission POEM-1. Based on the general interest in the data generated by this type of instrument, ESA selected MIPAS in 1989 as an 'ESA Developed Instrument' for POEM/Envisat-1.

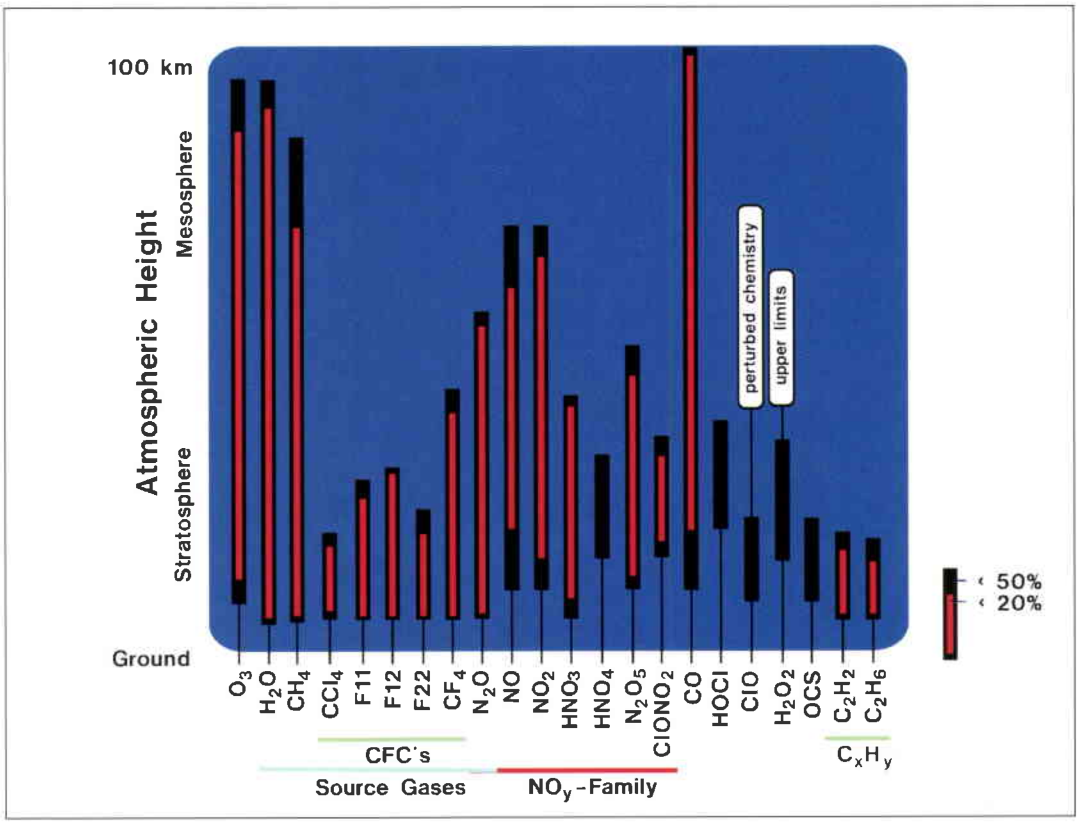
The MIPAS instrument for Envisat-1 is intended to provide new insights into the composition, dynamics and radiation balance of the middle atmosphere and the upper part of the troposphere. It will deliver calibrated high-spectral-resolution emission spectra of the atmosphere that allow one to retrieve concentration profiles of more than twenty trace gases and temperatures in the upper troposphere, the stratosphere and parts of the mesosphere.

Figure 1 shows the altitude range where the key atmospheric species can be detected by MIPAS. These data can be measured:
- simultaneously
- globally
- day and night
- throughout Envisat-1's four-year mission.

These data are important in particular for studies in stratospheric chemistry, global climatology, atmospheric dynamics and also tropospheric chemistry.

In *stratospheric chemistry*, we need to understand more thoroughly the processes that control the concentration fields of trace species, particularly the concentrations of major radicals and all major source gases, plus aerosols and polar stratospheric clouds. In recent years, most interest has centred around the ozone distribution, due to its depletion on an almost global scale. The complexity of the chemical reaction schemes and the coupling with dynamic processes are evident, so that the need for simultaneous and global measurements is obvious. MIPAS's main contribution in this area of research will be the detection of the entire family of nitrogen–oxygen compounds, as well as several CFCs, especially in the polar regions.

Figure 1. Altitude coverage of atmospheric species measurable by MIPAS



For *global climatology*, long-term measurements are required to improve our knowledge about variability and increases in atmospheric constituents in the troposphere and stratosphere, which affect our climate. In particular, knowledge of the global distributions of the major greenhouse gases H_2O, O_3, CH_4, N_2O and CFCs and of the atmosphere's temperature would aid investigations of the potential problems of global warming.

MIPAS is designed to provide the good stability, the high calibration accuracy and the long lifetime required to study global variability for all climate-relevant trace species, and to study trends in the concentration and distribution of some of the species of interest, although long-term changes will not be detectable for all species during Envisat's four-year mission duration. The relatively strong increase in CFC concentrations should certainly be measurable, however, and the predicted temperature decrease in the stratosphere of about 1 K every three years should also be detected by MIPAS.

An area of major interest in the field of *atmospheric dynamics* are exchanges of trace species between stratosphere and troposphere. MIPAS should contribute here by observing the concentrations of a number of trace constituents whose gradients of mixing ratio change markedly in the vicinity of the tropopause.

The troposphere is not a region readily accessible to MIPAS, but in areas without high clouds it will be possible to observe its upper part. Therefore, MIPAS data can be used to further our understanding of some of the major uncertainties facing *tropospheric chemistry*. In particular, NO_x concentration is important as it is believed that its concentration patterns are correlated with industrial activities, oceans and air corridors.

The MIPAS instrument

To achieve the scientific objectives outlined above, MIPAS will have to meet stringent measurement requirements in conducting the limb-sounding observations for which it is designed (Table 1). To achieve good height resolution, as most signal comes from the tangent-point region, the vertical extent of the instrument's instantaneous field of view must be narrow. For MIPAS, it is only 3 km high at the limb, corresponding to a 0.05° viewing angle. Horizontally, the field of view is 30 km wide, in order to collect sufficient radiance (Fig. 2).

To determine the concentration profiles of the atmospheric trace species, MIPAS will measure a series of spectra from different tangent heights. One basic elevation scan sequence will comprise 16 high-resolution spectra (or up to 75 spectra with reduced spectral resolution) and will take 75 s (corresponding to about 500 km of spacecraft forward motion). A typical elevation scan will start at about 50 km tangent height and descend in 3 km steps to 5 km, but it will be possible to programme different elevation scan sequences within the 5–150 km tangent height range, even with variable step sizes.

MIPAS will be able to make measurements in either of two pointing regimes: rearwards within a 35°-wide range in the anti-flight direction, and sideways within a 30°-wide range on the anti-Sun side. The rearward viewing range will be used for most measurements, as it will provide good Earth coverage including the polar regions. The sideways viewing is important for the observation of special events, such as volcanic eruptions, trace-gas concentrations in major air-traffic corridors, or concentration gradients across the dusk/dawn terminator.

As a result of the limb viewing geometry, the distance between instrument and tangent point is between 3000 and 3300 km, depending on the tangent height. Thus, in order to measure at a predetermined tangent height, the elevation pointing accuracy of both instrument and spacecraft must be excellent. The goal is to determine the geometric limb height from spacecraft-pointing information with a standard deviation of less than 600 m. A line-of-sight pointing knowledge with respect to nadir of better than 0.01° (1 σ) will be required. Very high alignment stability of all assemblies affecting pointing is a design driver for both MIPAS and the Polar Platform.

MIPAS's spectral-coverage range is from 4.15 to 14.6 micron (2410–685 cm^{-1}), which covers almost the complete mid-infrared region, and thus the emission lines of many atmospheric species are present. A Fourier-transform spectrometer is ideally suited to performing such wide spectral coverage measurements.

Table 1. Summary of MIPAS performance requirements

Observation geometry	
Instantaneous field-of-view	3×30 km^2 (height × width)
Elevation pointing range	5 – 250 km above Earth horizon
Azimuth pointing range	35° rearwards, 30° sideways
Spectral coverage	
Spectral range	685 – 2410 cm^{-1} (14.6 – 4.15 μm)
Spectral resolution (unapodized)	0.035 cm^{-1} (0.006 nm at 4.15 μm)
Spectral resolution submodes	Selectable in range 0.035 – 0.35 cm^{-1}
Radiometric requirements	
Radiometric sensitivity (NESR)	70 – 2 nW/(cm^2 sr cm^{-1})
Absolute radiometric accuracy	1% (at 14.6 μm) – 3% (at 4.15 μm) of input radiance, with an offset of 2 NESR
Measurement duration	
Time per spectrum	4.6 s (full spectral resolution) 1.0 s (1/10 spectral resolution)
Time per elevation scan	75 s (500 km ground trace)
Spectra per elevation scan	16 (full spectral resolution) 75 (1/10 spectral resolution)
In-orbit lifetime	4 years

The high spectral resolution of better than 0.035 cm^{-1} (corresponding to 0.06 nm at 4.15 micron) is necessary to resolve lines of specific constituents in the spectrum and to reduce the interference of overlapping spectral features. With this high spectral resolution, MIPAS will provide a total of 50 000 independent samples in each spectrum, which is measured within 4 s.

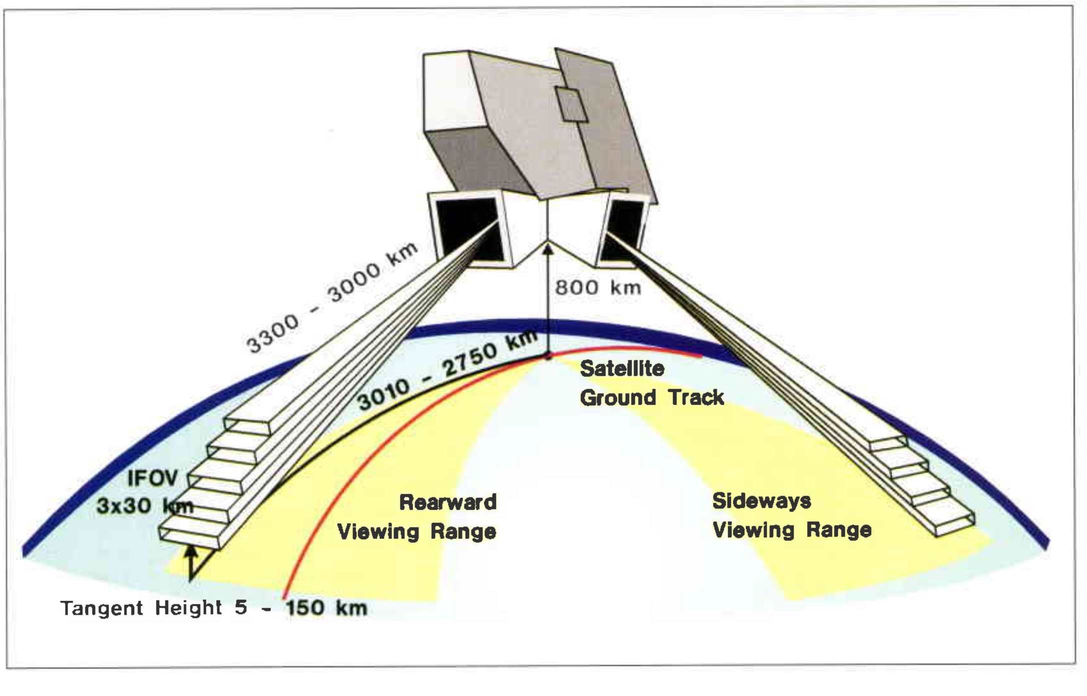


Figure 2. The MIPAS limb observation geometry

MIPAS is designed to perform measurements also with a lower spectral resolution in shorter times for special opportunities.

The radiometric requirements on MIPAS are also highly demanding. A good radiometric sensitivity is essential to allow the detection of weak atmospheric signals. Radiometric sensitivity is expressed here by the Noise Equivalent Spectral Radiance (NESR), which characterises the instrument noise in terms of incident radiance. The need for high radiometric sensitivity clearly requires low temperatures for all optical components, to reduce their own thermal emission, and also cryogenic detectors with high sensitivity.

The requirement on radiometric accuracy is also very stringent. A calibration accuracy in this range is difficult to achieve even for ground-based instruments. However, a good absolute knowledge of the received radiance is important in order to retrieve the atmospheric temperature profile, which is a key parameter for the determination of trace-gas profiles.

A last demanding requirement is an in-orbit lifetime of at least four years, to provide good data continuity and observation of atmospheric variability. This long lifetime represents a design driver for many components, particularly the interferometer with its moving optical components. Redundancy will be provided for all lifetime-critical subassemblies, and single-point-failure sources will be avoided as far as possible.

Figure 3 shows the overall layout of MIPAS as it will be mounted on the Polar Platform. It will consist of two separate assemblies:
– the Optics Module, with front-end optics, interferometer and focal-plane subsystem, mounted on the deep-space-viewing end of the Platform, and
– the Electronics Module, with signal processor, instrument-control electronics and cooler drivers on a common carrier plate located on the side near the Optics Module.

The Optics Module (Fig. 4) is about 1.32 m long (in the flight direction), 1.45 m high (nadir direction) and about 0.74 m deep (cold-space direction). It has a mass of about 130 kg. The total mass of MIPAS will be about 220 kg, and its power consumption is budgeted at 180 W.

Instrument performance and calibration
To meet the radiometric sensitivity requirements discussed above, all of MIPAS's optical elements need to be cooled to reduce their thermal emission. A trade-off has shown that active cooling of the Optics Module would allow the optics to reach lower temperatures, but would lead to a very complex instrument design. In fact, radiative cooling of the optics should be sufficient, and therefore only the detectors themselves

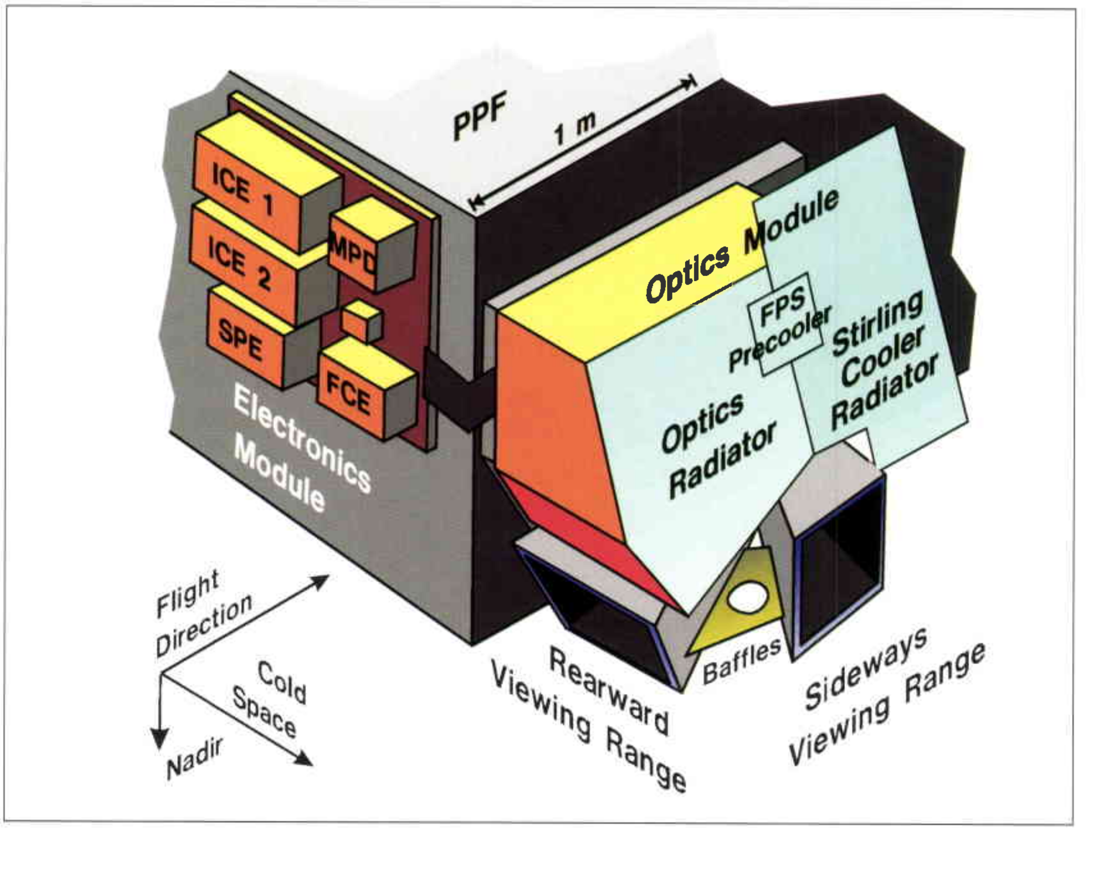


Figure 3. MIPAS mounted on the Envisat-1 Polar Platform

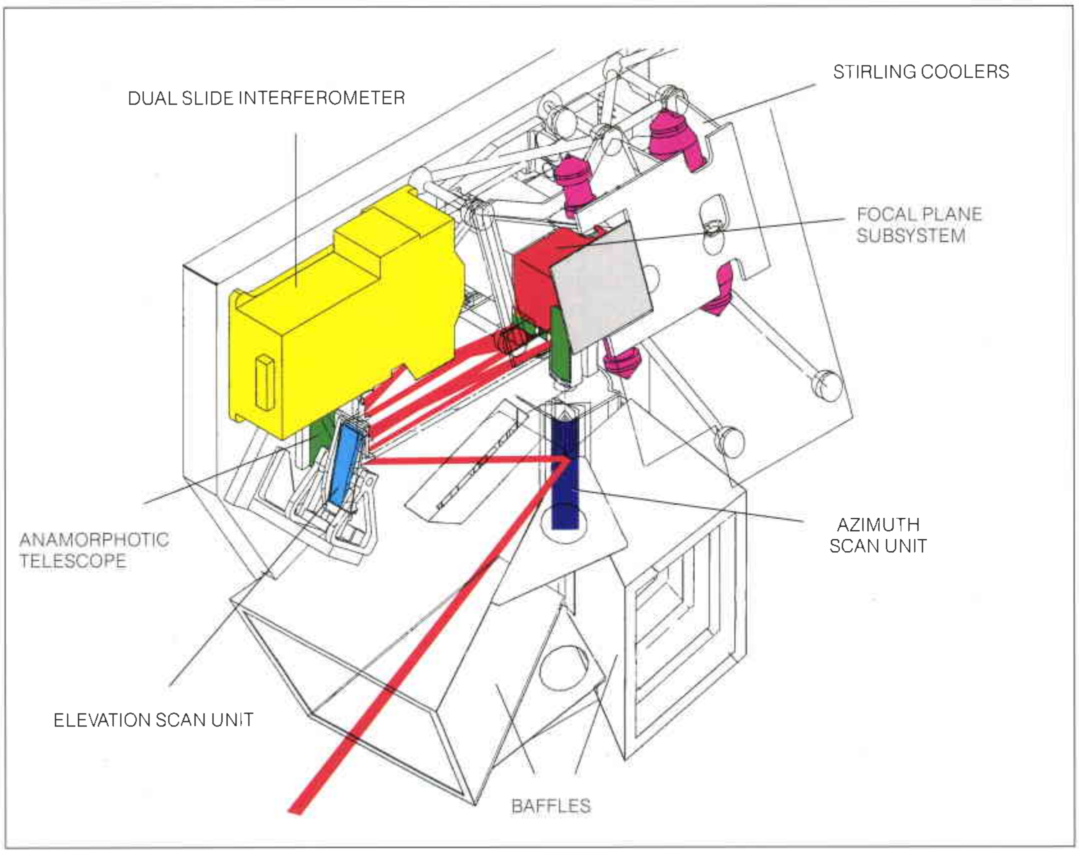


Figure 4. The MIPAS Optics Module

will be actively cooled. For these, a temperature of 70 K was found to be the optimum compromise between performance and instrument complexity.

Thus, the housing of the Optics Module carries three radiators:
- a large radiator to cool all optical components to about 200 K to reduce the thermal background
- two separate radiator surfaces to cool compressor and displacer units of the Stirling-cycle coolers that will lower the temperature of the focal-plane subsystem to about 70 K.

All radiators will be tilted away from nadir by 20° to reduce Earth shine, thereby improving their efficiency. This tilt gives the Optics Module its distinctive wedge shape.

Below the Optics Module will be the two baffles that reduce the amount of stray light entering MIPAS. The baffle for the rearward viewing range will extend sufficiently far from the first optical component to avoid sunlight, the most critical situation occurring when the South Pole region is observed during summertime. In this case, the minimum angle between Sun and line-of-sight could become as little as 5°.

The MIPAS instrument will require regular in-orbit calibration to ensure optimum performance. Radiometric calibration will be performed using two measurements:
- offset calibration, by observing cold space to determine the contribution of the instrument to the measured signals
- gain calibration, by observing the internal calibration blackbody source to calibrate instrument response throughout the spectral bands; gain calibration will also provide the information about the optical phase of the instrument, which will be needed for phase correction during ground processing.

Offset calibration will have to be performed frequently to follow the instrument self-emission, which will change due to temperature variations. Offset calibration after each elevation scan sequence (every 75 s) is envisaged. This calibration, taking less than 15 s, consists of several low-resolution interferometer sweeps that will be co-added by the ground processor to reduce noise.

Gain calibration will be needed much less frequently, the goal being once per week. A series of blackbody/cold-space measurements will be performed at low resolution, which will be co-added on the ground to achieve the required accuracy. The temperature of the calibration blackbody will also be downlinked to provide the basis for the conversion into an absolute radiance standard.

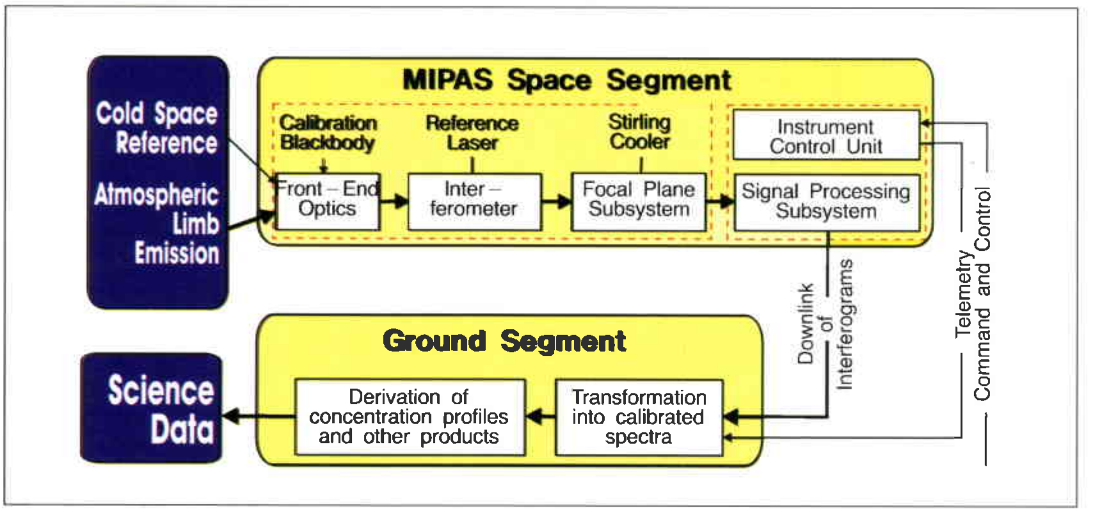


Figure 5. Data flow through the MIPAS space and ground segments

Product processing

Figure 5 is a functional block diagram of the MIPAS space and ground segments.

The atmospheric radiance enters the MIPAS instrument's Front-End Optics. From the Telescope, the radiance will be directed to the Interferometer, where the two moving reflectors periodically vary the phase of the incoming light. The resulting interference produces an intensity modulation of the transmitted light, which is recorded as a function of the phase difference between the moving reflectors by the Focal-Plane Subsystem. This 'interferogram' represents the Fourier transform of the incoming spectrum, which is transmitted to ground, after first being digitised and filtered by the Signal-Processing Subsystem.

In the Ground Segment, the interferograms will be converted into calibrated atmospheric spectra. At the subsequent processing levels, these spectra will be used to retrieve concentration profiles for the relevant atmospheric species, as well as atmospheric temperatures and other higher level data products.

Conclusion

MIPAS represents a new type of spaceborne instrumentation that will deliver high-resolution atmospheric spectra. These spectra can be used to derive concentration profiles for many atmospheric constituents of the Earth's middle atmosphere and upper troposphere. It will be the first cooled Fourier-Transform Infra-red Spectrometer in space, and it will allow the concentration profiles of many important trace constituents to be measured around the globe, and also in the polar regions in particular.

The performance requirements for MIPAS are demanding, especially the need for high radiometric sensitivity and accuracy, but also those concerning the pointing performance. The current design is considered a good compromise between achievable performance and development risk. It nevertheless employs many novel features and faces many challenges, including:
- maintaining interferometer and subsystem alignment over a wide temperature range
- designing and qualifying the laser interferometer
- understanding the potential lifetime and performance limitations of the dry-lubricated interferometer bearings
- avoiding contamination of the optical surfaces to ensure good stray-light suppression and the required radiometric sensitivity throughout the instrument lifetime.

Acknowledgement

We would like to thank the other members of the MIPAS Science Advisory Group for their support during the instrument-definition process, and particularly H. Oelhaf and C. Blom (of the Institut für Meteorologie und Klimaforschung, Karlsruhe, Germany), L. Delbouille (Institut d'Astrophysique de l'Université de Liège, Belgium), D.H. Ehhalt (Institut für atmosphärische Physik der Kernforschungsanlage Jülich, Germany), J.M. Flaud (Laboratoire de Physique Moleculaire et Applications, CNRS, Paris, France) and C. Mueller (Institut d'Aeronomie Spatiale de Belgique, Brussels).

The design work for the MIPAS instrument is being performed by an industrial team lead by DASA-RT (Ottobrunn, Germany), the MIPAS instrument prime contractor.

Envisat's Earth Radiation-Budget Instrument: SCARAB

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The SCARAB instrument was proposed by CNES as an Announcement of Opportunity instrument for Envisat-1 following the withdrawal by NASA of the CERES instrument originally selected as part of the POEM payload complement. SCARAB (Scanner Radiatsionnogo Balansa) will make an essential contribution to the monitoring of the Earth's radiation budget, which is a key element in our climatic system. Its data can also be used to refine existing climate models.

SCARAB's role

The dynamics of the Earth-atmosphere system are determined by the energy input to the system and its distribution, transformation and storage in various forms (Fig. 1). Earth radiation-budget measurements made at the top of the atmosphere involve most of these processes. The reflectance of incident energy and the upward flow of energy emitted by the Earth-atmosphere system exhibit large temporal and geographic variations and, as a result, the net radiation varies in time and space. This net radiation is the driving force for atmospheric and oceanic circulation and the associated energetics.

Satellite-borne instruments can provide the required observation of some of the radiation-budget parameters on a global scale and a number of such instruments have already been used to measure these quantities. The omni-directional sensors (flat-plate radiometers) flown on the Explorer-7 satellite back in 1959 are one example. Because of the orbital parameters and narrow field of view of these earlier instruments, most of the methods involved computing daily average 'top of the atmosphere' values for the reflected solar fluxes and corresponding emitted thermal radiation.

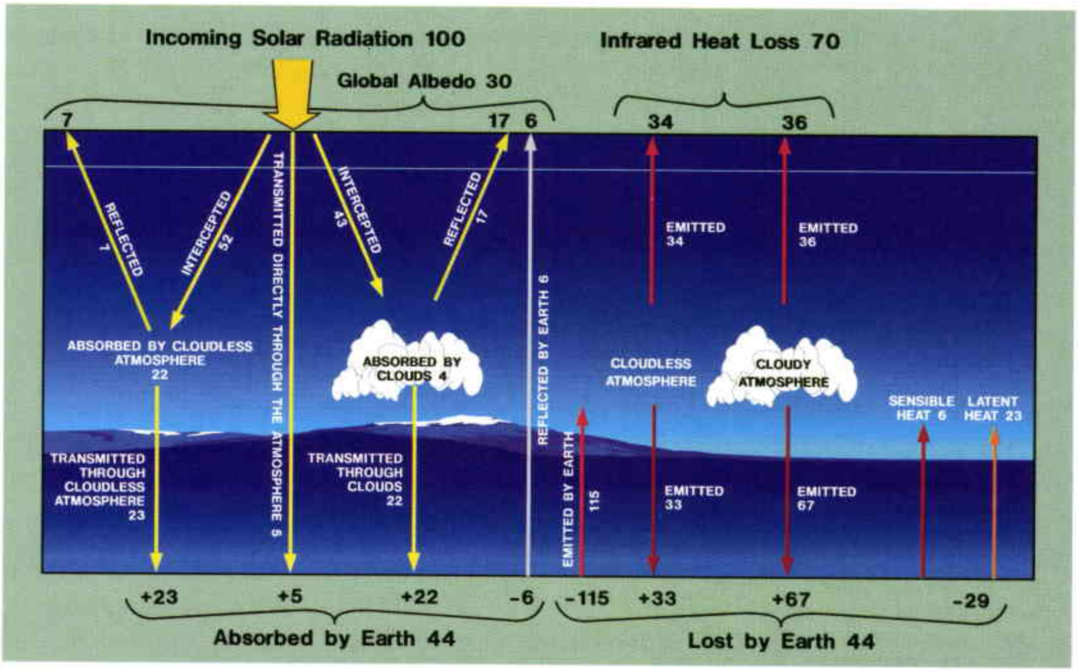

Figure 1. The energy balance of the Earth/atmosphere system (incoming solar radiation taken as 100 units). Under equilibrium conditions, the incoming solar energy at the top of the atmosphere is balanced by the reflected solar energy and thermal infrared heat loss. The energy balance at the surface involves sensible and latent-heat components

With the instruments flown on the operational Tiros and NOAA series of satellites, the albedo is determined from the visible channel by assuming that:
(a) the reflectance in a narrow spectral interval is a good estimate of the full spectral reflectance
(b) the observed reflectance is isotropic and independent of solar zenith angle
(c) there is no diurnal variation in the reflecting surface.

In the case of the Nimbus satellites, the albedo is determined from an instrument with a wide spectral channel and corrections for the anisotropic nature of the reflecting surface have been applied. However, no diurnal corrections are applied to the various reflecting surfaces.

From measurements made by these satellites, outgoing long-wave radiation has also been computed from radiances observed in narrow spectral channels using a regression formula derived from an atmospheric model covering a broad range of temperature and moisture values, as well as overcast and clear-sky conditions. In all of these derivations, corrections for dependence on solar zenith angle have been performed using a statistically derived 'limb darkening' function.

To a certain extent, the approach adopted for deriving the radiative fluxes from these instruments has had of necessity to be somewhat simplistic. A new generation of instruments and models is therefore being developed to address these deficiencies. These new instruments are being designed to measure the total outgoing long-wave and reflected short-wave fluxes, and mathematical models are being developed to handle angular variations in reflected solar radiation and the anisotropic nature of the reflecting surfaces.

It should be emphasised that satellite measurements only provide the radiative fluxes at the top of the atmosphere. They do not observe radiation-budget parameters at the Earth's surface. However, techniques are being developed to estimate the surface quantities from satellite measurements. For this, in order to obtain total information on the overall Earth-atmosphere radiation budget, it is essential to integrate the satellite radiation measurements with the data from other sources.

The Earth's radiation budget is altered significantly by aerosols, clouds and water vapour. The impact of increasing levels of aerosols and clouds on the radiation budget is difficult to assess as the distributions of both vary drastically in time and space, in shape and chemical composition (aerosols), and in general characteristics (cloud-top height and optical thickness). Thus, in addition to observations of top of the atmosphere fluxes, complementary global inventories of aerosol and cloud properties, as well as atmospheric water-vapour contents, are required on a long-time-scale basis in order to acquire a deeper understanding of the Earth's radiation balance.

In short, therefore, observation of the Earth's radiation budget requires broad-band measurements spanning long periods of the discriminating clear-sky and cloudy areas, with temporal sampling adequate (less than 100 km) to minimise biases arising from diurnal variations. Complementary information on the properties of aerosols and clouds is needed to reduce uncertainties related to radiative feedback processes associated with their presence. These appear to be a critical factor in accounting for the large spread in model estimates of climate sensitivity.

Over the past 25 years, the NASA Nimbus Earth radiation-budget missions and the more recent Earth Radiation Budget Experiment (ERBE) have established the ERB climatology with continually improving measurement accuracy and increasing sophistication in terms of the treatment of spectral corrections and angular/temporal sampling problems in the data processing. However, because increasing atmospheric concentrations of greenhouse gases are expected to lead to significant climate changes, the existing ERB data set will not suffice, but must be continued and extended. The current ERBE scanning radiometers ceased operation in February 1990 and the next series of NASA radiometers (i.e. the CERES instrument, an improved ERBE) is not scheduled to fly until 1998 at the earliest.

Recognising the need to minimise the gap in ERB data, France, in collaboration with Germany and Russia, has therefore developed the SCARAB instrument initially for flight on the Russian Meteor-3 series of polar-orbiting satellites. The first of these instruments is due to be launched in 1993, with a second launch in 1994 into an orbit whose plane is perpendicular to the first to provide at least four observations every 24 h, which are necessary for sampling the diurnal cycle.

The need to continue and extend these observations has prompted the decision to include a SCARAB instrument on Envisat-1 also (Fig. 2). This has three principal attractions:
- It will help safeguard the provision of ERB data from the 'morning' polar orbit until well into the next century, a vital point given the need to acquire long-term data sets for climate monitoring and studies.
- It will provide an opportunity to make direct comparisons between SCARAB data and that from ERBE/CERES, so helping to reduce the ERB data gap.
- It should enable the quality of the ERB data to be enhanced as data from other instruments due to fly on Envisat-1 (described in this issue of the Bulletin) can be used to improve corrections to raw ERB data as well in the derivation of radiation profiles.

The data analysis will represent a major challenge as the correction of SCARAB data and the derivation of ERB profiles, etc. is not a straightforward task, but vital experience is already being acquired in this respect in preparation for the Meteor-3 flights.

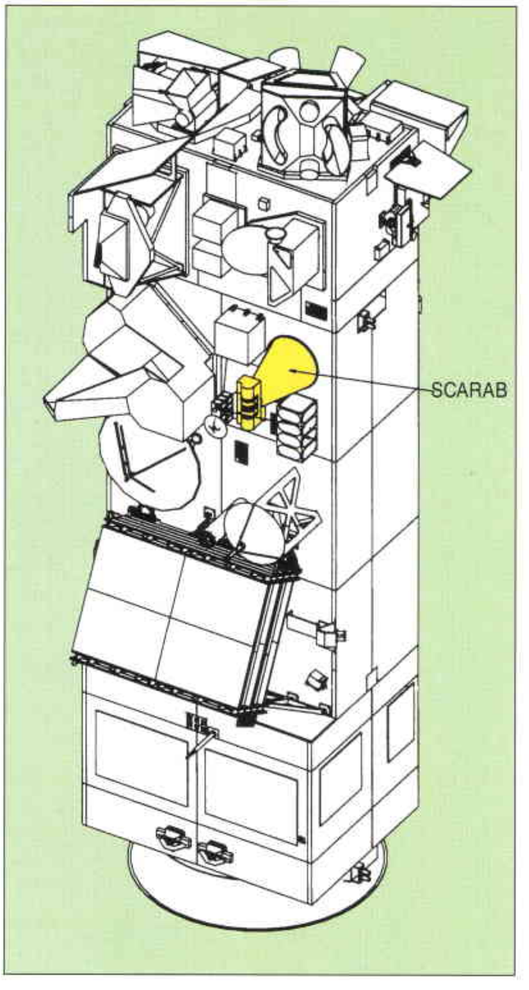

Figure 2. The location of the SCARAB instrument

The SCARAB instrument
The instrument for Envisat, derived directly from the SCARAB developed for the Russian Meteor satellite, is a cross-track scanning radiometer which includes four bands:
- Channel 1: Visible, 0.5–0.7 micron
- Channel 2: Solar, 0.2–4 micron
- Channel 3: Total, 0.2–50 micron
- Channel 4: Window, 10.5–12.5 micron.

Radiation in the long-wave band (4–50 m) is determined by differencing the measurements in Channels 2 and 3. Channels 1 and 4 are used as a link to operational imager channels and to aid cloud/scene identification.

The optical layouts of the four channels are identical. The incoming radiation is focussed by a spherical mirror directly onto a single electrical detector. The wavelength bands are selected by choosing the appropriate filters (Fig. 3).

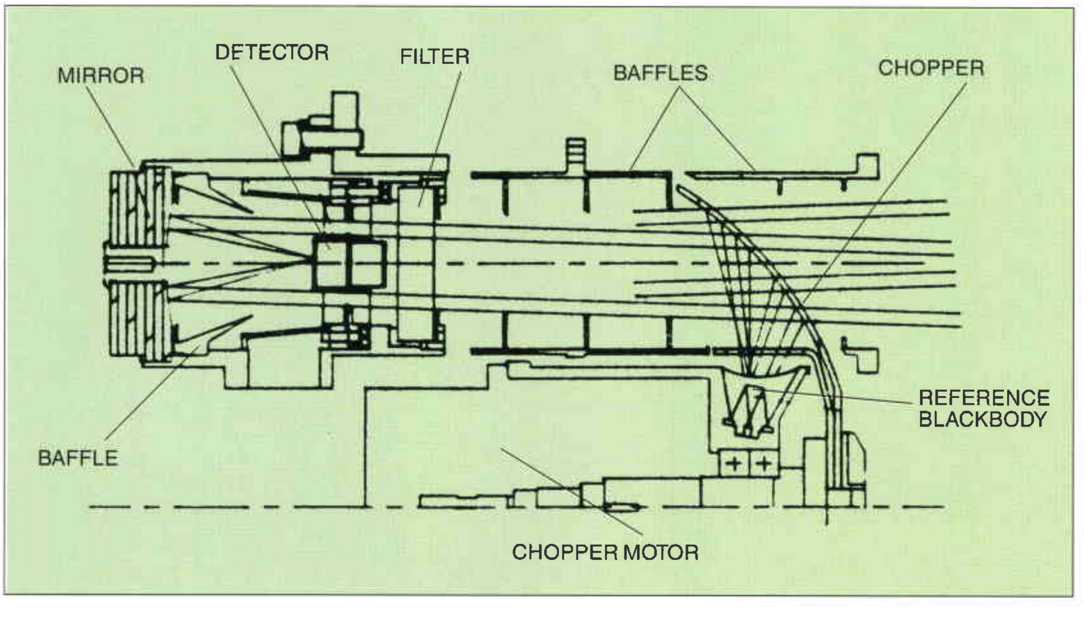

Figure 3. Channel optical layout

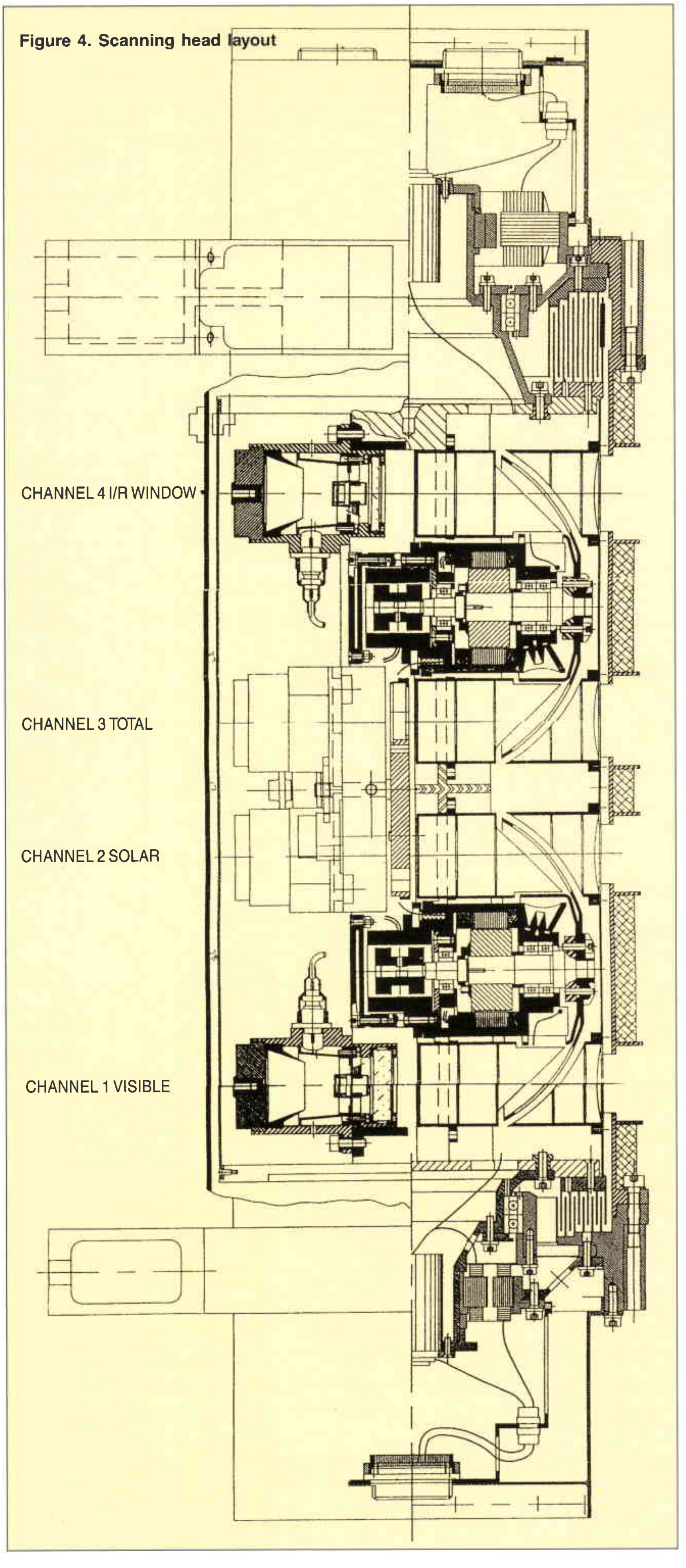

Figure 4. Scanning head layout

The four channels are mounted in parallel inside a cylinder that rotates about an axis perpendicular to the optical axis of the channels (Fig. 4). The radiation measurement is chopped by use of a rotating mirror and the chopping rate determines the pixel sampling frequency. The combination of scanning speed and chopper speed produces a pixel spacing of 42.5 km (to limit the aliasing). At Meteor-3's altitude of 1250 km, the pixel is 60 km square at nadir.

Instrument performance

The SCARAB scan cycle, covering about a 100° sector of the Earth's surface, takes 6 s. The offset is determined at each measurement cycle by observing deep space and the gain through measurement of on-board calibration sources:
- two blackbody simulators for the total and infrared window channels
- lamp sources for solar, visible and total channels.

In addition, the in-flight calibration strategy is based on the use of incandescent lamp sources. The ground calibration will be carried out at the Institut d'Astrophysique spatiale d'Orsay (F) and at the solar tower of the Kiepenheuer Institute Observatory in Tenerife (E).

The instrument performance parameters for SCARAB, as adapted for the Envisat orbit, are summarised in Table 1.

In addition to the interface adaptation from the Meteor unit, it is also envisaged to include:

Table 1. SCARAB expected performance and instrument parameters for Envisat orbit

Total channel	0.2 µm to 50 µm $L_{max} = 500$ W m^{-2} s r^{-1}
Solar channel	0.2 m to 4 m $L_{max} = 425$ W m^{-2} s r^{-1}
Relative radiometric accuracy	± 0.7 W m^{-2} s r^{-1} ± 0.0003 L (3 σ)
Absolute radiometric accuracy	± 2.5 W m^{-2} s r^{-1} ± 1.7% (LW) ± 3.5% (SW)
Spatial resolution at nadir	40×40 km^2
Scan period	6 s
Scan angle	100°
Pixel/scan	51
Sampling interval	34 mrad
Sampling period	62.5 mrad
Instantaneous field of view (IFOV)	48 mrad × 48 mrad

- a Sun calibration diffuser in addition to the on-board calibration sources
- active thermal control
- an improved instrument control unit that will allow extended command and control functions.

One possible configuration for the upgraded SCARAB instrument for Envisat-1 is shown in Figure 5.

Product processing
In the initial stages of processing the raw instrument data, transmission errors will be corrected and satellite location and attitude calculated as a function of satellite time. This pre-processed data, with raw calibration coefficients, validation information and house-keeping data, will be formatted and archived.

The definitive phase of the processing depends on the determination of in-orbit values for the radiances of the on-board calibration sources (as filtered by the four channels), since it is these values that will allow the computation of the channel gains. This is straightforward for the blackbody simulators, which provide the gains of the infrared (IR) window channel and of the long-wave (LW) portion of the total channel. For the visible and solar channels, as well as for the short-wave (SW) portion of the total channel, it is much more complicated. As the gain is determined by means of the stability of the calibration targets, it can only be determined by observing them over long periods, typically a few months.

The second stage of SCARAB data-product generation will be carried out in close collaboration with the scientists. Data inversion algorithms will provide instantaneous fluxes and daily and monthly mean values of Earth radiation-budget components, using instantaneous filtered SCARAB radiances together with models and auxiliary data (i.e. cloud and aerosol properties).

These products will be archived and will subsequently serve as input to the time-space averaging subsystem. The latter's goal will be to obtain unbiased monthly mean values of the 'Earth's Radiation Balance' (ERB) and an observational determination of 'Cloud Radiative Forcing' (CRF, a measure of the role of the clouds in climate), taking into account the diurnal cycle and providing a measure of monthly mean diurnal cycle.

The results of the time-space averaging phase will constitute the 'output' of the SCARAB experiment, namely data files giving mean quantities on spatial and temporal scales comparable to those of climate models. This, of course, does not preclude the use of these data by researchers interested in ocean analysis.

Figure 5. Possible SCARAB configuration for Envisat-1 (Courtesy of J. Pang, ESTEC)

Once validated, all SCARAB products will be archived and made generally available to the interested international scientific community (Table 2).

Table 2. SCARAB science data products

Basic data (filtered radiances in four bands):
- pixel by pixel in order of observation (scanning)
- unfiltered short- and long-wave radiances
- cloud/scene identification

Quasi-instantaneous regional mean values:
- for the entire clear-sky portion (latitude/longitude region of 2.5° x 2.5°)
- short- and long-wave radiant exitances, with regional statistics

Daily mean regional values and statistics:
- scene/cloud fraction

Monthly daily mean regional values:
- scene/cloud fractions and other statistics

Conclusion
Clearly, flight of the SCARAB instrument on Envisat-1 will make a major contribution to international Earth radiation-budget studies. Ideally, however, further flight opportunities for this and other radiation instruments are needed in order to acquire global data sets with sufficient frequency. One possibility that is currently being actively explored is that of also flying a SCARAB instrument on the Metop series of satellites (operational series of satellites being jointly studied by ESA and Eumetsat), the first of which is due to be launched in the year 2000.

Envisat's Radar Altimeter: RA-2

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The Radar Altimeter for Envisat-1, known as RA-2, is a fully-redundant, nadir-pointing pulse-limited radar operating via a single antenna dish at 13.575 GHz and at 3.2 GHz. Its design is based on that of the ERS-1 Radar Altimeter, but new features have been added in order to measure echoes from ocean, ice and land masses with improved accuracy and without interruption. The RA-2 instrument will therefore guarantee continuity of the observations started with its predecessor in order to satify the global Earth-monitoring requirement on a longer time scale.

RA-2's role

The main objective with the RA-2 instrument is to collect, on a global scale, calibrated samples of the earliest part of radar echoes from ocean, ice and land, and from their boundaries, without interruption. Ocean parameter estimation will then be performed via the on-ground processing.

Radar Altimeter measurements over oceans can be used to calculate mean sea level, ocean circulation (mesoscale and basin scale), wave height and wind speed, and for bathymetry. Measurements over ice contribute to determinations of ice extent, dynamics and mass balance. Over land, the Radar Altimeter can provide consistent elevation maps, the levels of lakes and rivers, and support water-shed modelling.

The RA-2 instrument: new features

The RA-2 design has been derived from that of the ERS-1 Radar Altimeter in order to minimise both development cost and risk. However, the new design includes several important modifications in order to improve its performance over the oceans and to enhance its operation over non-ocean surfaces without incurring significant increases in instrument mass and power consumption.

The new on-board processor will make RA-2 operations independent of surface type and modelling. Dedicated operating modes will no longer be necessary due to the autonomous on-board selection of the radar resolution. The increased number of independent measurements per second will reduce echo fluctuations and improve parameter estimation accuracy. The simultaneous operation of two channels at different frequencies provides a means of correcting altitude measurements for the effects of rapid spatial changes in ionospheric propagation.

Instrument operation

The main channel at 13.575 GHz (Ku-band) and the secondary channel at 3.2 GHz (S-band) will be operated continuously around the orbits with fixed pulse repetition rates. However, for every four pulses transmitted at Ku-band, only one pulse will be radiated at S-band, in order to minimise power consumption whilst still providing sufficient measurements for ionospheric correction. Only one channel will be operated at a time to allow the sharing of the most of the hardware.

Only the earliest part of the radar echoes will be sampled to collect scientific information with a low data rate and high resolution. A fixed number (128) of digital samples will be collected at radar resolution intervals from each echo within a tracking window. The gain and position of the latter will be continuously updated to match the distance and amplitude of the earliest part of the radar echoes received by the main channel (13.575 GHz).

The resolution can also be changed autonomously on-board to suit the tracking. Over open ocean, where the echo shape is well-modelled, the resolution should always be set at its highest value (0.46875 m). Over coastal zones, ice and land, where tracking could be lost due to the unpredictable and fast-changing echo shape, a coarser resolution (1.875 or 7.5 m) can be selected.

The echoes received by the secondary channel (3.2 GHz) are always sampled at a fixed resolution (0.9375 m) within a window whose characteristics are related to those of the main channel.

The samples from both the Ku- and S-band channels will be averaged over a fixed number of echoes – 100 and 25, respectively – to reduce fluctuations and data rates. These averages will be precisely time-tagged and transmitted to ground in formatted 'source data packets', each of which will cover about 1 second of radar operation. Internal calibration data, which will be routinely collected without interrupting radar measurements, will also be added to these packets. The data rate under these conditions will be limited to 64 kbit/s.

It will also be possible, by commanding from the ground, to store a limited number of individual echoes (2000) on-board the spacecraft. These data can be transmitted to ground by spreading them over about 100 source packets and increasing the instrument data rate to 100 kbit/s.

A summary of the RA-2 design parameters is presented in Table 1.

Product processing
On the ground, the samples of ocean echoes at the main channel frequency of 13.575 GHz will be fitted to a well-established ocean model and corrections and calibrations will be applied to estimate time delay, radar cross-section and standard deviation of the height distribution of the elementary surface reflectors. In this way, it will be possible to retrieve the spacecraft's altitude, the magnitude of the wind speed and wave height, respectively.

Major changes with respect to ERS-1
The main operating frequency of RA-2 has been shifted to 13.575 GHz, to avoid electromagnetic interference from Fixed-Satellite Earth to Space Services, which have recently been allocated new operating frequency bands.

In order to operate the secondary frequency channel at 3.2 GHz, the RA-2 antenna feed has been redesigned (Fig. 1). A solid-state power amplifier, a transmit/receive switch and a low-noise amplifier have been added. The subsystem that produces the necessary reference signals and the receiver have also been modified to support operations at the new frequency.

Table 1. Summary of RA-2 design parameters

Design parameter	Main channel	Common	Secondary channel
Altitude range, km		764 to 825	
Operative frequencies, GHz	13.575		3.2
Pulse length, μs		20	
Bandwidth, MHz	320, 80, 20		160
Transmitted peak power, W	60 (TWT)		60 (Solid/State)
Pulse repetition freq., Hz	1800		450
Number of echo samples		128	
Echo averaged on board	100		25
Antenna diameter, m		1.2	
Power consumption, W		168	
Mass, kg		106	
Data rate (nominal/max.), kbit/s		64/100	

Both the hardware and the software of the on-board processor are completely new. A dedicated Digital Signal Processor (DSP) performs a Fast Fourier Transform (FFT) on twice as many (128) digital samples in about half the time required by the ERS-1 instrument. The new algorithms that produce the error control signals are very linear and independent of echo shape. These characteristics, along with the doubling of the number of samples, make the new Radar Altimeter's operation very tolerant to changes in surface topography.

Furthermore, the width of the tracking window is autonomously selected on-board from three values. This is achieved by

Figure 1. The RA-2 antenna breadboard, with its dual-frequency feed

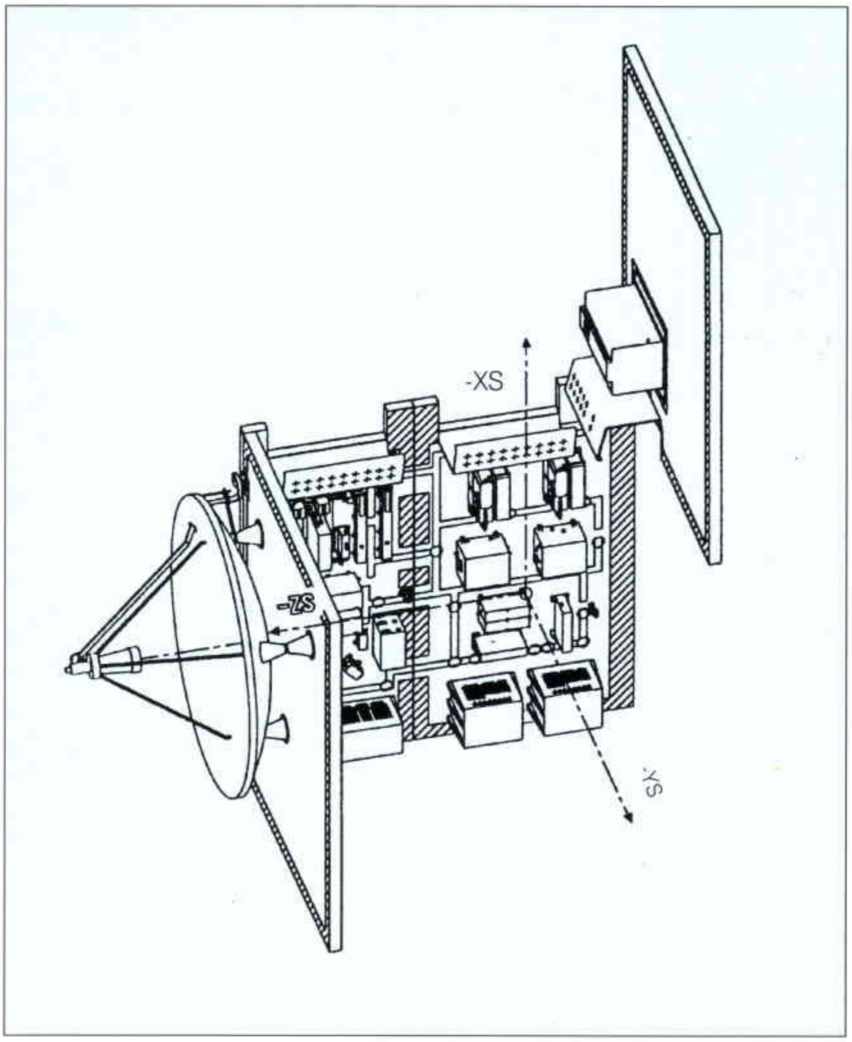

Figure 2. The accommodation of the RA-2 instrument boxes on the Polar Platform

Radar Altimetry

A Radar Altimeter on-board a satellite transmits electromagnetic pulses that propagate in a free atmosphere at the speed of light and it receives back the echoes reflected by the Earth's surface passing beneath the satellite. The radar measures the time that has elapsed between the transmission of a pulse and the reception of its echo, which is equivalent to the time that a pulse takes to travel twice the Earth-to-satellite distance. The latter can therefore be derived very precisely from this time measurement. The free electrons in the ionosphere and the water vapour in the troposphere slow down the speed of propagation, which must be accounted for to avoid incurring large errors in the altitude estimation. After corrections, and once the radar's orbital position is independently known, the altitude measurements can be used to accurately derive the Earth's surface topography. Over the oceans, the departure of the surface topography from the Earth's geopotential field (geoid) is caused by the equilibrium of forces generated by the Earth's rotation and by the ocean currents. The latter, which contribute greatly to the heat exchange between the equator and the poles, can ultimately be derived from the altitude measurements.

The Radar Altimeter is therefore an unique tool for studying the role that oceans play in the Earth's climate system and for understanding climatic change on a global scale.

changing the radar altitude resolution and maintaining the same number of samples. When the radar echo is about to move out of the tracking window, due for example to a sudden change in surface elevation, the window is broadened to re-capture it. This will allow uninterrupted radar operations over all kinds of surfaces, including their boundaries, and will avoid the need for dedicated operating modes commanded from the ground.

The radar pulse generator, based on Surface Acoustic Wave (SAW) devices, has been modified to generate Linear Frequency Modulated (LFM) pulses (known as 'chirps') in three different bandwidths selectable by the on-board signal processor.

The Pulse Repetition Frequency (PRF) of the main channel has been increased to 1800 Hz, to allow the averaging on-board of a higher number of independent measurements per second. Consequently, a fast DSP has been selected in order to allow each echo to be processed before the reception of the next one.

Some further changes have been necessary both to meet the new environmental requirements set by the Polar Platform and in order to cope with a mission lifetime of 4 to 5 years. All of the electronic boxes are fully redundant, and cross-strapping between five major assemblies provides for 32 different hardware configurations, assuring the necessary reliability. All of the units are housed in the Payload Equipment Bay (PEB) of the Polar Platform, which also provides mechanical support and thermal control for the complete instrument (Fig. 2).

Conclusion

The RA-2 instrument will probably be one of the first to be integrated into the Polar Platform payload complement because of its already advanced state of definition. The manufacture of the RA-2 Engineering Model (EM) will start soon after the Preliminary Design Review (PDR), scheduled for October 1993, has been successfully completed.

The measurements that Envisat's RA-2 instrument will make will contribute to a better understanding of our environment on Earth and will allow us to monitor it on a global scale.

The Legal Protection of Remote-Sensing Satellite Data

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As the commercialisation of remote-sensing data gathered by satellite grows, it is becoming increasingly important that a legal structure is established to recognise the status of the data and to protect the rights of those involved — the satellite operators, the instrument providers, and ultimately the data users. A solution based on a draft directive being prepared by the Commission of the European Communities is proposed.

One of the prime mission objectives of the Agency's Envisat-1 mission, to be launched in 1998, will be the monitoring of the Earth's environment in order to contribute to both the European and worldwide efforts that are being undertaken to manage and protect the environment effectively. Although Envisat-1 is financed from public funds committed by the ESA Member States, it is evident that the heavy financial burden of such programmes obliges those States to explore ways of sharing the costs with the private sector by promoting the commercialisation of remote-sensing data. However, private investors will only be tempted to participate if the business is profitable and if the legal framework provides sufficient security to protect them in the exploitation of the remote-sensing data.

The legal analysis

The European Centre for Space Law (ECSL), a research centre founded in May 1989 as an ESA initiative and which operates under the Agency's auspices, decided in 1990 to make the study of the legal protection of remote-sensing data one of its main objectives. After evaluating the results of a questionnaire that had been sent to industry, organisations and experts active in remote sensing, ECSL organised a workshop on this subject in 1991. Representatives of the Commission of the European Communities (EC) attended the workshop and, given the importance of the economic consequences of remote sensing, decided to join forces with ESA/ECSL.

The EC, with the support of ECSL, issued a call for tender for the study of the regulatory aspects of the protection of remote-sensing data. Professor Philippe Gaudrat, a professor of intellectual property rights at the University of Poitiers (France), was selected to undertake the task. He had previously served as a consultant to the EC in the area of intellectual property rights in telecommunications. He began the study in 1992 with a survey of the applicable national legislations in Europe and the United States. He submitted his final report at the beginning of this year. It confirmed that the existing legislations do not provide adequate protection of remote-sensing data and that solutions contained in international law such as multilateral treaties and other specific instruments are also not satisfactory.

However, in order to encourage industry to invest in remote-sensing systems, the law should provide for property or exclusive exploitation rights. The only complete protection on the basis of an exclusive right that exists in all national laws, and which is organised internationally, is protection by copyright/author's right.

Prof. Gaudrat states, however, that: "This protection, which many industries favour for its international dimension and its absence of costs, presents two major weaknesses in the case of remote sensing: it is unequally applicable to raw data that are transmitted by satellite and, under most national laws, it is difficult to apply it to automatically extracted photographs."

Prof. Gaudrat has identified a solution which, at least in Europe, would provide the required protection. The draft Directive on the Legal Protection of Databases of 13 May 1992, proposed by the EC (COM(92)24 Fol Syn 393), could, if slightly amended, provide an adequate legal

A proposed solution for the legal protection of remote-sensing satellite data

The draft EC Directive:	The proposed amendment:
– Harmonises conditions of access to database and protection by author's right	– To include in the definition of the database, the act of collecting data from Earth observation satellites
– Reduces required level of originality	– Inclusion of the above protects the database owner against unlawful extraction of data
– Creates its own right of extraction on the contents of the database	
– Covers only the database as a structured method of arranging and storing raw data, and not the complete chain of generated computer products, from original computer bits to extracted photos	

framework for the protection of remote-sensing data. Prof. Gaudrat explains the solution:

"Besides the fact that this Directive harmonises the conditions of access to a database and protection by author's right, and that it reduces the required level of originality, it also creates a *sui generis* right of extraction on the content of the database, which is independent of protection by author's right.

This double regime could allow coverage of the complete chain of computer products derived from remote sensing: even if we suppose that storage of raw data on board the satellite does not result in an original database in terms of the new criterion, the content of this non-original database (i.e. the flow of computer bits) would still be protected by the right of extraction; and if, at a later time, the conditions for protection of the database (or of the content) by author's right could be fulfilled, the intellectual property rights on the captured object would complement or replace the right of extraction. So this construction would protect all stages of the process, without interruption, from the transmission by the satellite to the delivery of the most sophisticated computer products.

Nevertheless, there is a double *conditio sine qua non* to cover remote-sensing activities satisfactorily by means of this instrument: on the one hand, the definition of databases must be sufficiently broad to cover the storage of scanned data on board the satellite; and on the other hand, the concept of the right of extraction must be sufficiently flexible to include the interception of a signal, and should not merely concern active intrusion into a system. But the term 'right of extraction' seems to privilege a 'hacker' attitude, whereas the Directive's definition of a database seems to be made for databases that are exploited on-line, rather than for raw data files stored on board a satellite.

We keep coming back to the same problem: What is the basic data of a database?

It is important to note that even though this instrument does not at present provide the security that we would expect, it does not expressly exclude a satisfactory scope. The fastest and most economic solution could therefore consist of assuring that proper interpretation will be made when the text of the Directive becomes the national legislation applied in each country. This is even more feasible now that the Directive is still in the process of being adopted and should soon be discussed by the European Parliament. The general report that accompanies the draft Directive suggests some modifications in order to resolve any ambiguities concerning the field of application of the future Directive.

Finally, in addition to, or instead of this solution, we may also think of the establishment of Community legislation (which will be harmonised *ab initio*) in order to meet those needs of the industry that are not fulfilled by existing incorporeal properties."

Circulation of data

As stated earlier, in order to attract private investment to the domain of data processing and distribution, and to furnish this activity with a proper framework, there is now an obvious need for legal protection. There is a growing concern about the applicable system and the best method to adopt for the circulation of remote-sensing data.

For all stages, from when the data is produced on-board the satellite in outer space, to its transmission, reception, processing and distribution, procedures have already been established through actual practice whereby the satellite operator plans and manages the different stages, culminating with the distribution to users. For this to be possible, the legal title over the data must be ascertained at each of those stages of data circulation, and for each of the data sets as they are separately produced, handled and used. At present, the holder of the data rights needs to stipulate conditions for the use of the data, according to either the nature and role of the holder or the final destination of the data. Today, there are several different examples of legal terms agreed either explicitly or tacitly between holder and user.

This is not intended to and should in no way impose restrictions on the general principle of open and non-discriminatory access for all interested users. In this case, freedom of access means the possibility for a user to apply for and obtain a copy of the data set while agreeing, however, to meet the conditions of the holder of the data rights.

The implication is that whoever has control of the satellite system or owns the data on the basis of a legal title can determine the conditions of access attached to a given data set before it is widely circulated. The international remote-sensing community is familiar with this entitlement and it is in fact the policy adopted by all space agencies that have a data-production capability. Data users also understand that certain conditions have to be met before they can access the data. Such conditions may include:

— recognition of the legal title and ownership of the data rights
— authorisation for the user to exploit the data, make additions and further process the data to derive modified data for specific applications
— the user's commitment to handle the data solely for the purpose of the agreed activity, not to make unauthorised copies, and not to redistribute the data to third parties without the prior consent of the holder
— correct indication of copyright, etc., when publishing the data
— any further conditions for circulation.

Different cases

The situation becomes more sophisticated in the case of data rights claimed by different entities who have some degree of involvement in the satellite mission. One example of this is the case of an entity providing a remote-sensing instrument (the instrument provider) to be flown on a satellite developed and operated by another entity (the platform operator). The basic understanding between these two entities will determine the type of arrangement and consequently the data rights of each party.

The ESA policy in this area is to provide flight opportunities for interesting instruments on-board its satellites on the assumption that the Agency remains the owner of all data resulting directly from the in-flight operation of the payload flown as part of an Agency programme. This flight opportunity is offered to the instrument provider on a free-of-charge basis, on the grounds of scientific and technical merit, and with the aim of benefiting the widest possible scientific and remote-sensing community with the products from the payload data in question.

The purpose of ESA's Earth Observation Programmes is to obtain the latest information on the Earth's resources and divulge it widely to users in a timely manner. The principles for the provision of data from ERS-1 already reflect the need for a wide distribution of the data on a non-discriminatory basis, as soon as they are technically available. In addition, the orientations for future policies concerning remote-sensing data indicate the increased need for data-circulation arrangements under different international schemes — either bilateral or multilateral — involving space agencies of several countries, in order to make the best possible use of the wealth of data flowing from such elaborate remote-sensing missions.

Conclusion

The inadequacy of the existing legislation applicable to such an important and growing industry presents us with a challenging situation. It is becoming more and more necessary to secure a sound legal basis for the qualification and recognition of the status of data emanating from payloads observing the Earth, calling for sophisticated yet effective legal reasoning. The far-reaching results expected from today's ambitious Earth observation programmes can only be optimised if supported by a solid legal framework whereby the satellite operators, the instrument providers, and ultimately the data users, are able to rely on a clear and widely acceptable set of arrangements.

Towards More Efficient Use of Radar-Altimeter Data

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The Committee on Earth Observation Satellites (CEOS) has been striving to standardise product formats since 1984, in particular through its Working Group on Data, which is also addressing networks, archiving, storage media, data management, etc. There is currently no clear consensus on how to build geophysical data sets so that users will never be caught off-guard by changes in product format.

In the case of radar altimetry, the ever-growing scientific community is still relatively small and traditionally 'digests' all available global data sets. Altimetry is thus an appropriate domain in which it should not be too ambitious to think about product harmonisation already at the geophysical data level.

Introduction

Twenty years ago, experimental altimeters on NASA's Skylab and Geos-3 were already demonstrating the potential of such instrumentation. This led in turn to the development and launch by NASA in July 1978 of the Seasat oceanographic satellite mission. Both Geos-3 and Seasat were very successful in their pioneering missions, but were limited somewhat by poor coverage in the case of Geos-3 and an abnormally short mission duration in Seasat's case.

Table 1. Radar-altimeter missions

Past missions	
Skylab	NASA, 1973
Geos-3	NASA, 1975–1978
Seasat	NASA, July to October 1978
Geosat	US Navy, data processed by NOAA, March 1985 to November 1989
Current missions	
ERS-1	ESA, July 1991–...
Topex-Poseidon	NASA/CNES, August 1992–...
Future missions	
ERS-2	ESA, 1995
Envisat	ESA, 1999
Topex-Poseidon follow-on (NASA/CNES)	
Geosat follow-on (US Navy)	

Nevertheless, the results that the international scientific community was able produce from the two missions were sufficiently promising for ESA and NASA/CNES to start developing the altimetric missions that are flying today, namely ERS-1 and Topex–Poseidon.

Geosat, initially a purely military geodetic mission which subsequently became a declassified oceanographic mission, bridged the gap during the second half of the eighties, furnishing the first long-term global-coverage altimetric data set.

The earlier pioneering missions and today's steady flow of data from ERS-1 and Topex-Poseidon have demonstrated beyond doubt that radar altimetry is a powerful, if complex, instrument concept that contributes to a better understanding of our planet's global climatic system and the effects of mankind's activities upon it. The following are just a few examples of what is being achieved by the international scientific community through the use of radar-altimeter data.

Sea level and the marine geoid

The spaceborne altimetric system – i.e. the radar altimeter itself and its ancillaries, such as the microwave sounder and tracking system – measures the range between the spacecraft and the surface below. Over the oceans this measurement is transformed into elevation of the sea surface (Figs. 1–3). This surface has a dynamic range of some 200 m and roughly represents the gravitational geopotential surface, called 'the geoid'.

The geoid represents the shape produced by the gravitational attraction of water at rest. The sea surface also contains small vertical displacements, of the order of 1 m, about the geoid, known as 'the dynamic topography', which is related to the ocean circulation (Fig. 4). In order to analyse the ocean dynamics, the geoid is subtracted from the measured sea surface.

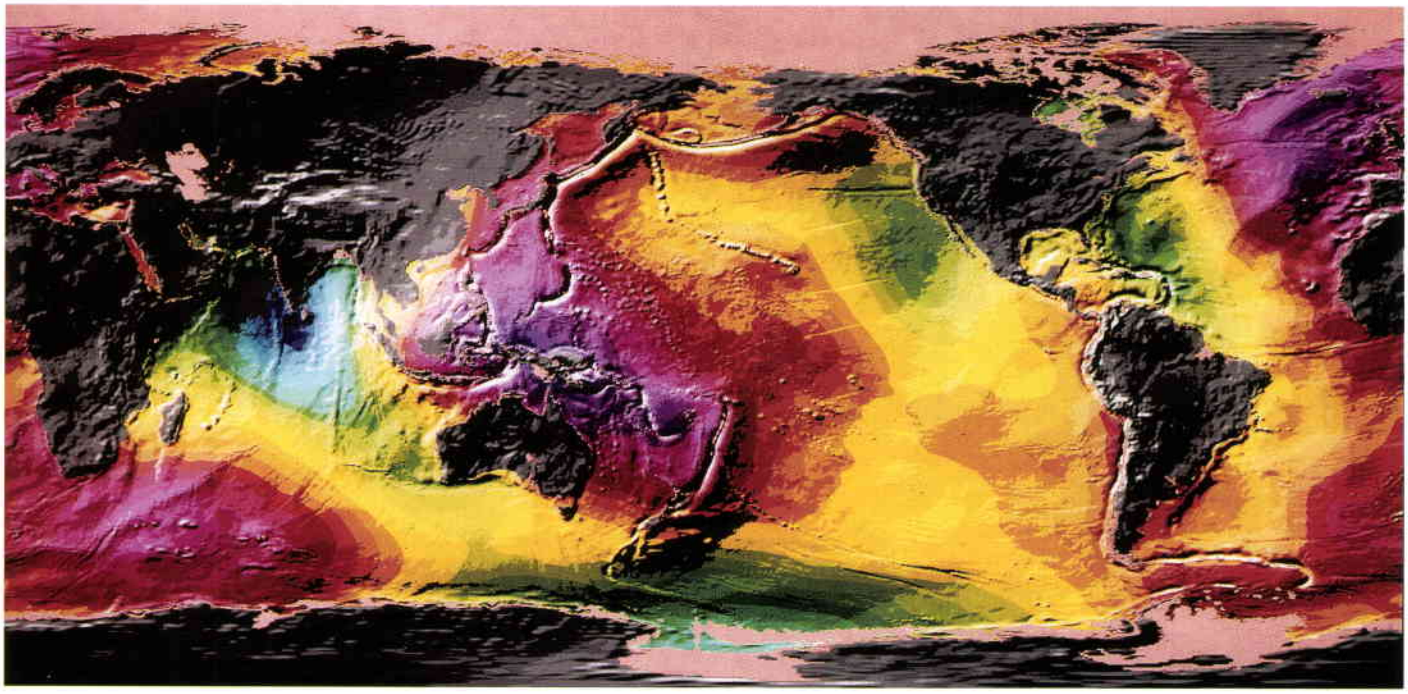


Figure 1. Global mean sea surface

Illuminated relief with coloured iso-contours of a sea-surface-height model. The latter is a digital data set consisting of a global set of sea-surface-height point values with respect to a reference ellipsoid. It was produced by the German Processing and Archiving Facility (D-PAF) from the Geophysical Data Records generated at the French PAF. Long- and short-term solutions are available. The long-term solution represents the mean sea surface over the longest time span available, updated every six months. The short-term solution is based on one 35-day or ten 3-day cycles.

(Courtesy of the German Processing and Archiving Facility)

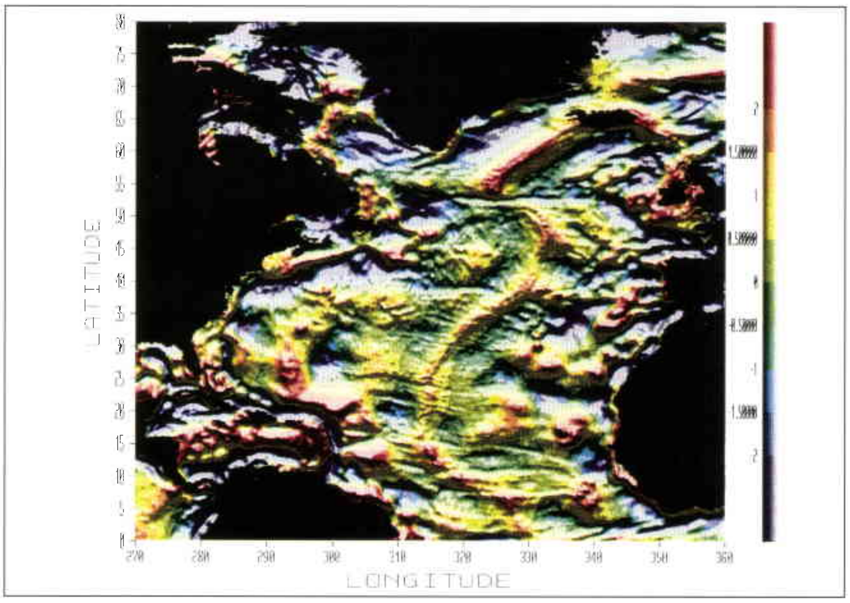


Figure 2. Mean sea surface of the North Atlantic

The heterogeneous shape of the mean sea surface, observed by Geosat, ERS-1 and Topex–Poseidon, is clearly visible in this map of the short-scale variations (variations with wavelength longer than 1500 km have been removed). The holes and bumps correspond to irregularities in the gravity field, which in turn reflect the heterogeneous distribution of mass in the Earth's interior and the presence of underwater relief.

The expected high resolution when ERS-1 is in its 176-day orbit cycle will lead to a major improvement in this map, and thus in our understanding of the Earth's interior.

(Courtesy of Groupe de Recherche en Geodesie Spatiale)

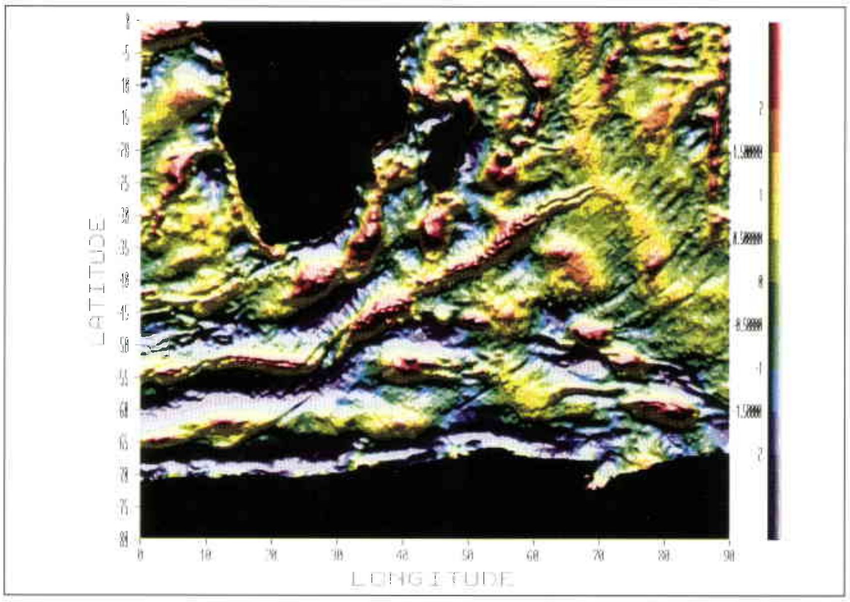


Figure 3. Same as Figure 2, but for the Southeast Indian Ocean

(Courtesy of Groupe de Recherche en Geodesie Spatiale)

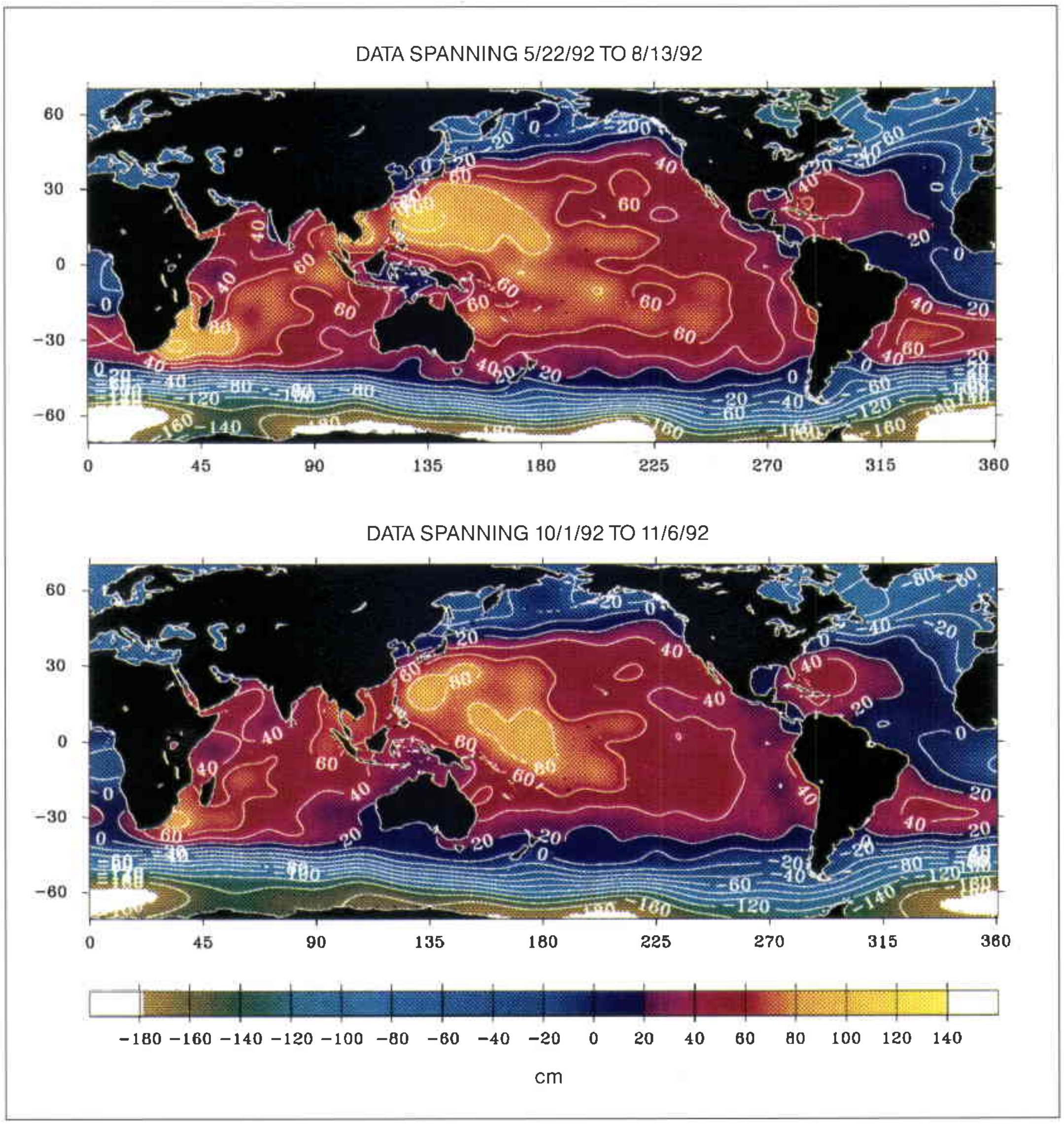


Figure 4. Dynamic ocean topography as observed by ERS-1 during Summer 1992

ERS-1 altimeter data were reduced to sea-surface heights using precise orbits computed at UT/CSR. The dynamic topography was filtered to keep only the large scale. The strong currents occur where the iso-contours are close together.

(Courtesy of Univ. Texas Center for Space Research)

Today, the geoid is not known to sufficient accuracy at wavelengths below 3000 km. In order to increase our understanding of ocean behaviour, dynamic topography must be distinguishable from the geoid at mesoscale wavelengths, say of order 100 km. Moreover, knowledge of the geoid per se is an important step towards understanding the dynamics of the Earth's interior. A radar altimeter can also be thought of as a tracking device onboard an orbiting platform integrating the Earth's gravity field. Altimetric missions therefore contribute to improving our knowledge of the gravity field (Fig. 5).

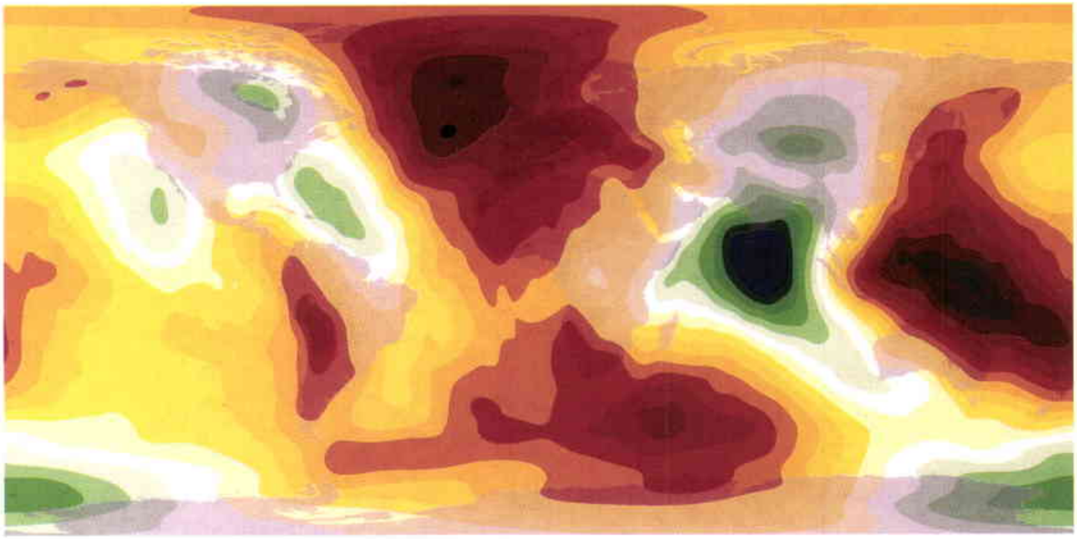


Figure 5. The improved Earth gravity-field model used for ERS-1

The gravitational geopotential produces the principal acceleration on Earth. A precise orbit restitution applying dynamic methods therefore requires a precise model of the geopotential with a resolution requirement depending on the satellite's altitude. The Earth does not have a uniform gravity field; it is weaker south of India than in Indonesia.

(Courtesy of German Processing and Archiving Facility)

If the absolute sea level is still difficult to assess, methods have been developed for observing the variations in ocean circulation. They are based on the analysis of the differences between two sets of measurements. The steady gravitational contribution to sea level contained in the two sets of measurements is removed and the varying part can then be analysed. This is achieved by observing differences between successive overflights of the same ground track, or by observing differences from points where ascending tracks cross descending tracks, called 'cross-overs', or by differencing the altimeter measurements along the track to derive the 'slope' of the sea level. The idea is that the inadequately known geoid is removed during the differencing process and thus local variations can be mapped.

Figure 6 shows the mesoscale variability computed as the standard deviation of the sea-level slope between April 1992 and June 1993, extracted from ERS-1 radar-altimeter data. The main current systems playing a key role in heat exchange can be detected and their variability quantified.

Sea-level variations involve a broad range of space and time scales. Mapping of temporal variations in currents at intermediate scales (300–3000 km) and basin-wide circulation requires an orbit determination precise to the sub-decimetric level. Precise orbit computation is dependent on a permanent flow of good-quality tracking data and a state-of-the-art gravity model. The quality of the altimetric measurements is directly dependent on the quality of the orbit computation.

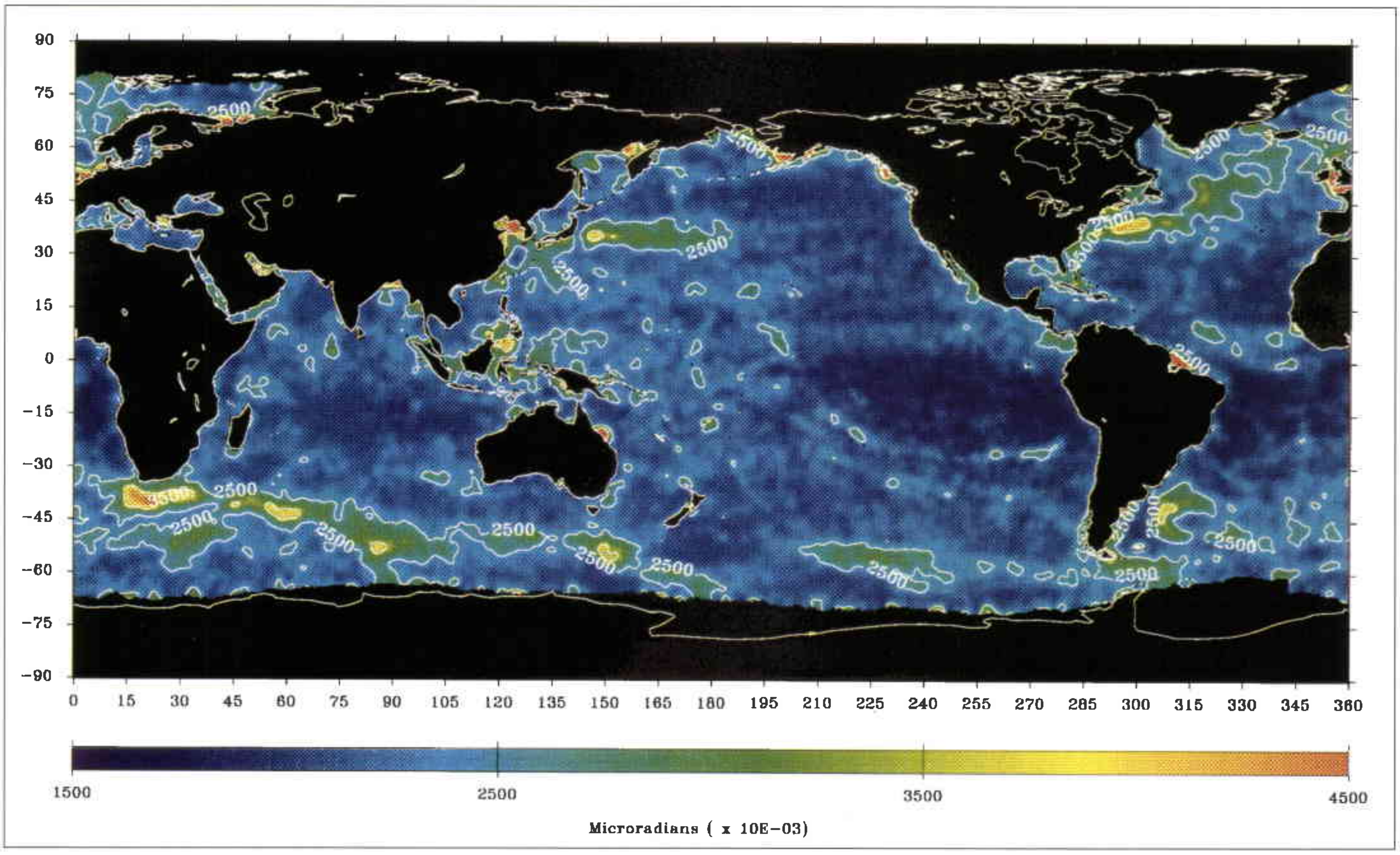
Outstanding progress has been achieved in the past five years by the international groups working on precise-orbit computation, by constantly exchanging data and actively working together. For example, the ERS-1 operational precise-orbit computation has been drastically upgraded and new orbital ephemerises are being re-computed for the whole mission.

The El Niño is another such large-scale phenomenon. In response to the weakening of the Trade Winds, the sea level in the eastern Pacific becomes higher than normal and the South American west-coast upwelling of cold and oxygen- and nutrient-rich water stops. One of the immediate local outcomes is that the anchovies migrate or die, resulting in a shortage of fish for human consumption and of the anchovy flour used to feed cattle. Ultimately, corn flour must replace fish flour during an El Niño year. The climatic impact of El Niño is not yet fully fully understood, but it is already clear that it is global, affecting all weather patterns (colder winters in the Northern Hemisphere, droughts in Australia).

Figure 6. Mesoscale variability

This figure indicates the global current system as seen by ERS-1 during the first year of its 35-day repeat cycle. The main currents stand out as regions of high variability due to the sea surface changing substantially more than in regions where there are no large currents present.

(Courtesy of Univ. Texas Center for Space Research)



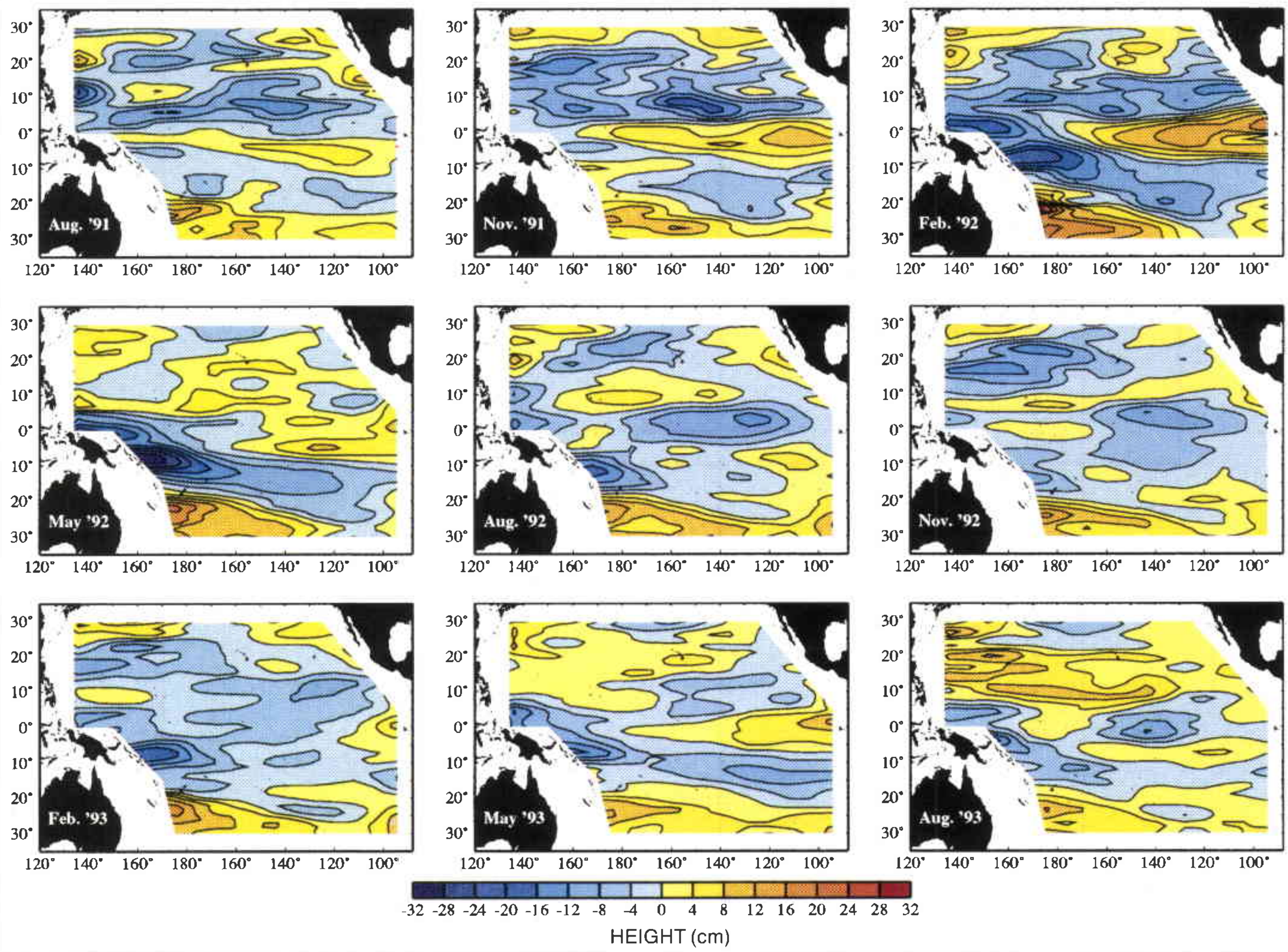


Figure 7. Maps of sea-level anomaly from ERS-1 altimeter data

In response to anomalous winds, an El Niño situation began in Winter 1991 and peaked in Spring 1992. The sea level returned to normal by Autumn 1992. This phenomenon has a period of three to seven years. The second, unexpected, warm event started early in 1993.

(Courtesy of J. Lillibridge & R. Cheney, NOAA)

The ERS-1 radar altimeter has been used to monitor two El Niño events so far (Fig. 7).

Ice-sheet altimetry

Almost 94% of all water on Earth resides in the oceans, whilst 1.5% is stored as snow and ice, most of which is to be found in Antarctica. The short-term drivers of sea-level change are the relatively small mountain glaciers whose typical variation time scales are of the order of 100 years, compared with 10 000 years for changes in Antarctica. The Greenland ice sheet's variability lies somewhere in between. Thus, mountain glaciers are believed to be sensitive indicators of climate change, but their impact on today's sea-level changes might be blurred by the Antarctica ice sheet still adjusting to past changes in climate.

Whatever the origin, the lag and the time scale, the volume of water frozen in the cryosphere (the ice and snow milieu) is ever-changing. Measuring the rate of that change is mandatory for sea-level change prediction. Very little is yet known about the actual mass balance of the cryosphere. Past glaciological research efforts have indicated that ground-based measurements cannot provide the requisite monitoring of the ice volume. ERS-1's polar orbit, taking it over the far north and far south of the globe, is allowing it to gather data of unprecedented value in terms of ice-sheet elevation monitoring.

In addition, ERS-1's radar-altimeter tracking system has a special agile mode that allows it to cope with steeper relief without losing track. Previous radar altimeters designed primarily for satisfactory tracking performance over the ocean tended to lose the signal from their tracking window when the topography became steep. In addition, the return power profiles, or 'waveforms', reflecting from sea ice or land masses do not have the same characteristics as ocean returns in that they are more spiky. The instruments' tracking algorithms did not perform properly on such land/ice waveforms, which had to be re-analysed on the ground to re-estimate the range – a process known as 're-tracking'.

Unfortunately, previous radar-altimeter missions could not cope either with extensive data downlinking, and so the raw data were first compressed on board. Consequently, the ground 're-trackings' were not done using all of the original waveforms, but based on an average, from which it was not possible to calculate errors accurately. The ERS-1 radar altimeter downlinks waveforms at twice the rate of previous missions, thereby permitting more accurate re-tracking.

ERS-1's radar-altimeter data over ice will provide the necessary information for many glaciological studies, such as delineating catchment basins, characterising flow lines, calculating ice-flow driving stresses, setting boundary conditions for numerical models, producing accurate digital elevation models, mass-balance studies, identification of the equilibrium lines between accretion (accumulation) and ablation (melting or iceberg carving).

Waves
As the power reflected from the troughs of ocean waves arrives later than the power from the crests, the significant wave height can be deduced from the return-power waveforms. The wave-height measurements from the radar altimeter are used for sea-state forecasts for such real-time applications as ship routing, offshore operations, coastal engineering, and the prediction of flooding.

Figure 8 shows a monthly distribution of significant wave heights over the global oceans.

Wind
Wind speed over oceans is retrievable from radar-altimeter data because the wind stress on the sea surface affects its backscattering properties. Figure 9 shows a monthly distribution of wind speed over the global oceans.

In addition to its meteorological application, radar-altimeter wind modulus is also used to correct microwave-sounder measurements.

Modelling and assimilation
The above are just a few examples of the variables that a radar altimeter can monitor. In many instances, a variable determining the state of a system, say the ocean, is monitored by several independent measuring instruments. None of these instruments ever procure a complete description of the state of the observed system. The individual measurements themselves also often include small errors or suffer from sampling limitations.

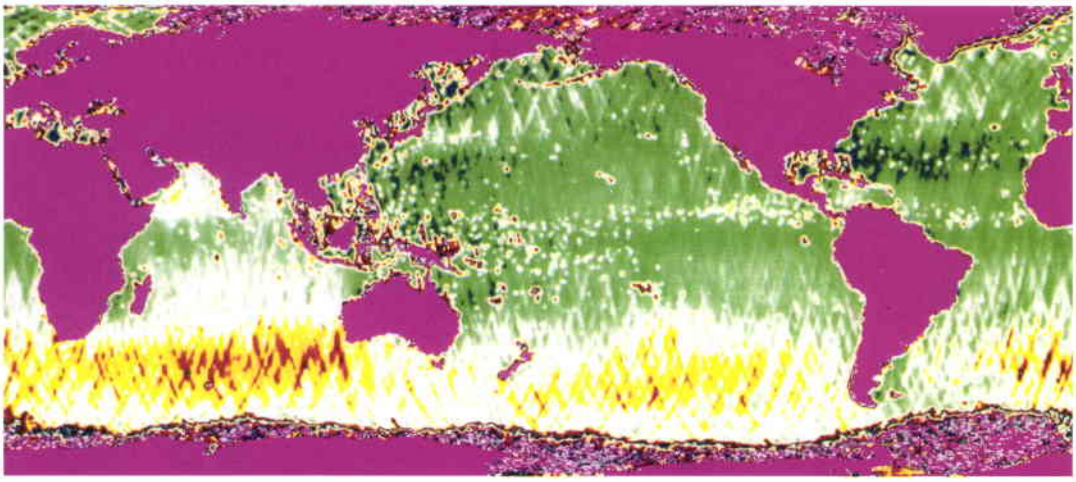


Figure 8. Significant wave height from radar altimetry

The significant wave height is derived from the analysis of the return echoes of the ERS-1 radar altimeter. This data is globally sampled and available within the quick-look sea-surface product which covers one full repeat cycle (35 days), generated every week. This sample is for 27 April to 1 June 1992.

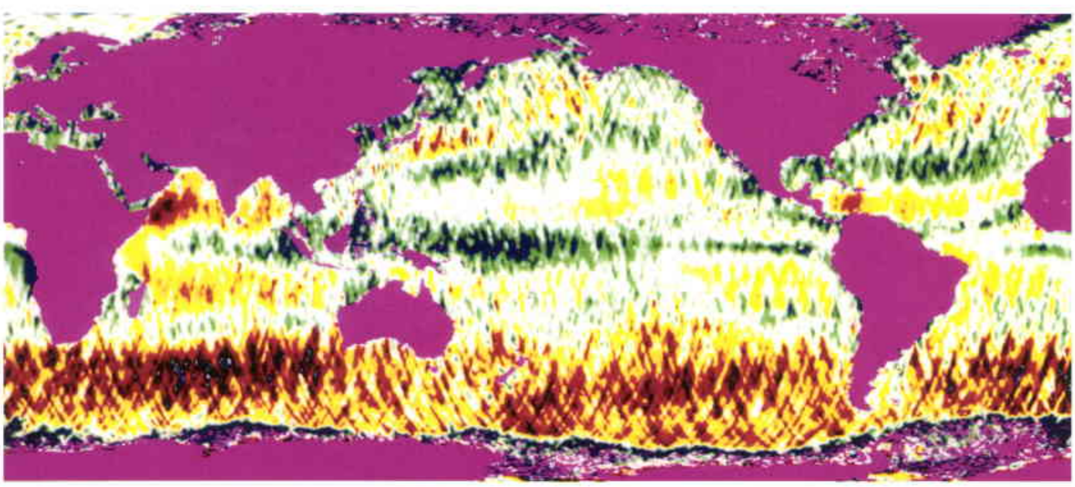


Figure 9. Wind speed from radar altimetry

The nadir wind speed is derived from analysis of the return power of the ERS-1 radar altimeter. This data is globally sampled and available within the quick-look sea-surface product which covers one full repeat cycle (35 days), generated every week. This sample is for 27 April to 1 June 1992.

The solution is to make optimal use of each data set, separating and rejecting the errors and extracting the real signals from the measurements. To do so, it is important to have a good statistical description of the likely errors in the various measurements. The limitations of each instrument can then be taken into account in the data-combination process by assigning weighting factors to the various data sources based on their likely error content.

To illustrate the concept of combining data from different instruments in this way, one can consider that sea level can also be measured by shore tide gauges, by bottom pressure gauges, by inverted echo sounders, by measuring temperature and salinity profiles, etc. Satellite altimetry benefits directly from such in-situ measurements during the calibration and validation phases of each mission, but there are tremendous gains to be realised when all such data measuring the same variable, but obtained with very different approaches, are optimally combined.

This is usually best organised around a numerical model and an assimilation scheme to absorb the different data sets and extrapolate the information in space and time. Such a numerical-model approach is the key to extrapolating the large amounts of sea-surface information collected by radar altimetry to the interiors of the World's oceans. Even in a context not relying on a numerical model, the improvement that can be expected from combining data from two or more altimetric missions is not one-sided for the less-accurate data sets; in addition to the obvious accuracy improvement, merging data from two or more radar-altimeter missions immediately improves both the temporal and spatial resolutions.

Combining ERS-1 and Topex–Poseidon altimeter data, for example, means that the shorter-scale (both temporal and spatial) signals can be resolved and detected for the first time, rather than being aliased into larger-scale signals.

Preparing the user data products

Before any data can be combined with other data or assimilated into numerical models, or even used directly, they have to be processed from 'instrument level' into meaningful geophysical units. The former levels can include anything from raw electrical signals downlinked to the receiving stations, to their computer-processed counterparts. The data sets at the latter level are the so-called 'Geophysical Data Records' (GDRs). The meteorologist interested in wind speed expects his anemometer to read in metres per second, not volts created by the dynamo. The users of space-acquired data expect no less from the satellite system.

The ground segment must therefore be designed not only to gather the radar-altimeter data, but also to prepare it for the users. Beyond generating the GDRs per se, this complex task includes flagging the slightest inconsistency in the instrument output, such as a perturbation of the micro-wave measurement over the ocean due to the presence of a small island. The data produced must also be verified to guarantee their quality, and efforts invested to refine or develop processing algorithms. To best channel these efforts and to optimise the generation and use of the data, the producing agencies and the users must maintain close contact.

Today, ERS-1 and Topex–Poseidon are providing complementary altimetric data. ERS-2, Envisat, a Topex–Poseidon follow-on mission, and a Geosat follow-on mission are planned. Each of these missions is dedicated to monitoring different geophysical signals, with different sampling strategies. As explained above, no observing system is completely self-sufficient. The simultaneous operation of these new altimetric missions will greatly enlarge the scope for cooperation in radar-altimeter and microwave-sounder (ATSR/M on ERS) sensor evaluation and product validation, in addition to the prime geophysical goals.

Given this new multi-mission environment, such issues as sensor cross-calibration, inter-consistency of processing algorithms, product specifications, and external data sources must be defined, solved and verified in a consistent manner. Only by doing so will we be able to guarantee that users will be in a position to straightforwardly and confidently exploit data from these missions. The goal must be to harmonise the altimetric Geophysical Data Records from the various missions and their quality assessment, and thereby further optimise their quality.

At the beginning of an era in which climatic and economic circumstances dictate that we should monitor our planet closely, the pace of data acquisition can be expected to increase dramatically. This makes it even more crucial that we put every effort into simplifying the data usage, or in other words into making the measuring chain more efficient.

ESRIN is intending to unify and augment the tools necessary to generate fast-delivery products from the ESA instrument data, to control and evaluate them, as well as be able to cross-calibrate and cross-evaluate between ESA's missions. ESRIN is therefore developing a precision processor for ESA's altimetric mission instruments – radar altimeter and microwave sounder – uniquely dedicated to sensor, algorithm and product evaluation, external to the routine operations environment and capable of dealing with data products from multiple missions. This tool will be used in future definition, implementation, testing and upgrading of fast-delivery altimetric user products and systems.

A lesson that has clearly emerged from all previous radar-altimeter missions is that there is a need for an intensive algorithm-validation and engineering-assessment effort early in each mission, in addition to the regular development phases. Success can only be achieved with the appropriate tools.

Conclusion

The two ERS missions and the future Envisat mission (extensively described in this Bulletin) cannot be considered in isolation. They are inevitable stepping stones for the success of the World Research Climate Programme. Further missions are also being planned, as continuity of altimeter measurements is essential in order to study long-term changes in ice and sea-surface topography, for climate studies and climate change prediction.

The advanced data users will always seek the optimal solution by exploiting as many different data sources as possible. In addition to standardising storage media and product formats, therefore, standardisation of the 'Geophysical Data Records' emanating from the various radar-altimeter missions, as well as of the method of quality and error-budget estimation for each remotely sensed variable, is an essential ingredient for the optimal use of future earth-observation data.

Figure 1. The Hubble Space Telescope with its two solar arrays fully extended at the moment of release from the Space Shuttle.

The Hubble Space Telescope First Servicing Mission

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In December 1993, the first mission to service the Hubble Space Telescope (HST) will be launched. It is based on a servicing mission concept that has been in place for more than 15 years, whereby the HST receives periodic upgrading in orbit rather than returning the telescope to Earth. Both the Space Shuttle crew, one of the most experienced ever selected by NASA, and the ground crew have thoroughly rehearsed each activity that they will perform during the mission.

The servicing mission concept
From the time of start-up of the Hubble Space Telescope (HST) in 1977, it was realised that the HST could not remain unchanged throughout its planned 15-year lifetime. Just as ground-based observatories require periodic upgrading so the HST needs modification on a routine basis. Following analysis, it was decided that for financial and scientific reasons, it would be better to do this in orbit, through servicing missions, rather than by returning the telescope to Earth. It was therefore decided to plan to have servicing missions to the HST about every three years throughout its lifetime. The discovery of spherical aberration in the telescope's optical system soon after launch gave an added impetus to the First Servicing Mission, scheduled for December 1993.

There are four major reasons for servicing missions:

— To replace scientific instruments with those having more technologically advanced detectors and components
— To improve subsystem design where operational experience has shown that improvement is needed
— To replace failed or defective units
— To raise, when necessary, the orbit of the HST which, with time, would otherwise gradually decay.

An important implication of the decision to perform in-orbit servicing was that all instruments had to be designed *ab initio* to facilitate it, taking into account the difficulties the astronauts would face in accessibility and handling. This was the first time that such an approach had been taken and, although the complexity of designs increased, particularly in such systems as the solar arrays, the planning for the First Servicing Mission has shown it to be worthwhile. This First Servicing Mission is the forerunner of a series of planned, routine operations to extend the life of the HST and to ensure that it remains a state-of-the-art observatory.

The payload of the 1993 Servicing Mission
The full complement of the hardware to be carried in the Shuttle for the 1993 Servicing Mission is shown in Table 1. Since it is a very extensive list, all items may not be able to be installed in the HST in the allocated number of Extra-Vehicular Activity (EVA) days. The main objective is to install the primary items.

Table 1. Hardware to be carried on the Shuttle for the First Servicing Mission

Primary items to be installed:
- Wide Field/Planetary Camera II (WFPC-II)
- Corrective Optics Space Telescope Axial Replacement (COSTAR)
- Space Telescope Solar Array 2 (STSA-2)
- Two gyroscope units (RSU-2 and RSU-3 electronics)
- Magnetometer-1
- Solar Array Drive Electronics (SADE) unit

Secondary items to be installed:
- Goddard High Resolution Spectrometer (GHRS) repair kit
- Magnetometer-2
- DF-224 Coprocessor
- Gyro-1 fuses (RSU-1)

The well-publicised error in the shape of the secondary mirror in the HST has caused results from some instruments to be degraded and has made it difficult, if not impossible, to carry out some investigations originally planned for the HST. The Corrective Optics Space Telescope Axial Replacement (COSTAR) is a set of mirrors designed to compensate for the existing spherical aberration and thereby restore almost the full capability of the remaining instruments. In particular, it will extend the range of the European-provided Faint Object Camera to allow it to see even more distant objects. It will replace the High Speed Photometer in the telescope instrument bay since that photometer has been one of the lesser used instruments in the HST.

The Wide Field/Planetary Camera (WFPC) currently on the HST is the most used of the scientific instruments. However, its design dates from 1977 and, because of the major advances made in detector and component technology in the last decade, it will be replaced by a more modern instrument, which incorporates internal compensation for the spherical aberration of the HST. For similar reasons, at least one magnetometer system will be replaced by one of a more modern design.

From early in the design phase of the HST, it was recognised that the solar array mounted prior to launch would not be capable of providing adequate power for the HST throughout its projected 15-year lifetime because of the normal deterioration of solar cell performance after extended exposure to the hostile environment at HST orbit, including ultraviolet radiation and atomic oxygen attack. Therefore, even before the HST launch in 1990, a second array was being built. After launch, a small 'jitter' was found in the HST. It was caused by a flexing of the solar arrays as the spacecraft passed from sunlight to shadow and vice versa during each orbit. It was decided to modify the second array and to include it in the 1993 Servicing Mission to enhance the HST's performance in this area also.

Finally, gyroscopes are always regarded as a potentially weak link in any spacecraft and the HST is no exception. Although the spacecraft is still fully functional, some gyro units have failed and will be replaced in order to restore full redundancy in this critical area.

In May 1993, the primary Solar Array Drive Electronics (SADE) unit failed and, although a redundant unit is operational in the HST, the primary unit will be replaced by a refurbished Flight Spare Unit. This will be done because the SADE controls the slewing of the solar arrays to be sun-pointing whatever the attitude of the HST, and the loss of both units would restrict the HST's scientific capability.

Although all other items of the Shuttle Payload complement listed in Table 1 are important, they are regarded as secondary to those described above and they will be installed into the HST if time permits. Also, if time allows, the HST will be boosted into a slightly higher orbit to allow for subsequent orbit decay.

The modifications to be introduced to the HST during the 1993 Servicing Mission therefore fulfil the objectives of the servicing mission concept, i.e. to introduce more modern technology instrumentation (WFPC and magnetometer), to improve subsystem design (COSTAR and the solar array), to replace failed units (gyros and SADE) and to raise the orbit of the spacecraft to prolong its working life.

Outline of the 1993 Servicing Mission

The HST First Servicing Mission, known in the Shuttle world as STS-61, is currently scheduled to be launched at 09.30 GMT on 1 December 1993. The Space Shuttle 'Endeavour' will be used because it has more capabilities than the rest of the fleet. In many ways, the mission will be one of the most complex undertaken by NASA, with a total of five scheduled EVA days and three contingency EVA days. Depending upon the number of EVA days actually needed, the total mission duration, from lift-off to landing (both at Kennedy Space Center), will be between 11 and 14 days.

The seven-member Shuttle crew (Fig. 2) selected for this complex mission is one of the most experienced ever nominated by NASA. Each member has flown at least once before and, between them, they have a total of 16 Shuttle flights and over 2500 hours in space.

Whilst all crewmembers have a wealth of experience, special mention should be made of two of them. At 58, Story Musgrave is the oldest active NASA astronaut; he has flown on five shuttle launches and has spent 598 hours in space. He will lead the EVA crew. Claude Nicollier is Swiss and an ESA astronaut on secondment to NASA. He is a

Figure 2. The crew of the 1993 Servicing Mission. Front row (from left to right): Ken Bowersox (pilot); Kathy Thornton, Story Musgrave and Claude Nicollier (mission specialists). Back row: Dick Covey (commander); Jeff Hoffman and Tom Akers (mission specialists).

specialist in operating the Remote Manipulator System (RMS), the Shuttle's hinged arm used to manoeuvre equipment or astronauts around the cargo bay during EVA. This RMS will play a vital part in the HST First Servicing Mission. (See the related article 'European Astronaut Training in Houston' in this issue.)

The general mission outline for each EVA day is shown in Figure 3. One primary payload item is central to each EVA day, and the secondary items are grouped around it. With some limitations, the days are constructed on a modular basis, both within the day and with respect to other days. In that way, if there is a small delay in a planned activity, another task can be performed without undue loss of valuable EVA time. Similarly, if a major problem arises, it is possible to substitute an alternative day thus allowing time for detailed consultations.

Table 2 shows some of the main features of the mission related to Mission Elapsed Time (MET) and GMT.

During each EVA, two astronauts are actually working outside the Shuttle. There are therefore two teams of two crewmembers,

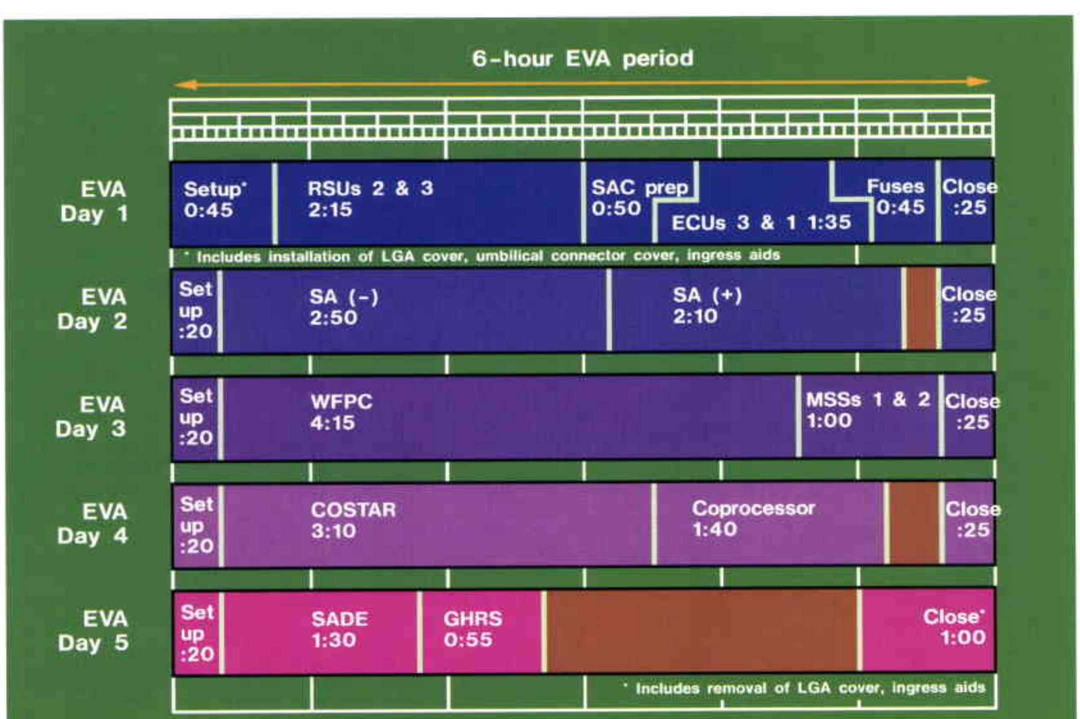


Figure 3. Mission outline for each EVA day. The time at the beginning and end of each EVA is for preparing and stowing work areas. The brown areas are contingency periods.

each team taking alternate days of EVA. Nominally the teams are Musgrave/Hoffman and Akers/Thornton but all astronauts are cross-trained so that they can replace each other if necessary

The change-out of the HST solar array
During the Servicing Mission, the astronauts will change a number of HST units. These so-called change-outs follow essentially the same pattern — remove the old unit and store it in a temporary location, install the new unit, and place the removed unit in a permanent location for transport back to Earth.

Table 2. Summary timeline for the mission in relation to Mission Elapsed Time (MET) and Greenwich Mean Time (GMT)

MET	Major Event	GMT		
D H M		D	H	M
00:00:00	Shuttle launch (1 December 1993)	335	09	30
01:03:00	Close HST aperture door	336	12	30
01:23:45	Manipulator arm grapples HST	337	09	15
02:00:40	Berth HST			
	EVA-1:			
02:19:35	Change out Gyros 2, 3 and Magnetometer-1	338	05	05
03:01:35	Prepare SAC for SA change out	338	11	05
03:02:15	SA +V2 Wing retraction	338	11	45
03:03:30	SA −V2 Wing retraction	338	13	00
	EVA-2:			
03:19:35	Change out SA	339	05	05
04:01:35		339	11	05
	EVA-3:			
04:19:35	Change out WFPC	340	05	05
05:01:35	Install GHRS repair kit	340	11	05
	EVA-4:			
05:19:35	Replace HSP with COSTAR	341	05	05
06:01:35	Change out Gyro electronics 1, 3	341	11	05
	EVA-5:			
06:19:35	Change out SADE-1, Magnetometer-2 and fuse plugs	342	05	05
07:01:35	Install DF224 co-processor	342	11	05
07:02:20	SA +V2 Wing deployment	342	11	50
07:04:00	SA −V2 Wing deployment	342	13	30
07:20:05	Manipulator arm grapples HST	343	05	35
07:21:00	Unberth HST	343	06	30
07:21:1-	Manoeuvre HST to release position	343	06	40
07:23:20	Open HST aperture door	343	08	50
08:00:45	Release HST	343	10	15
10:21:45	Orbiter landing	346	07	15

The change-out of the solar array (Fig. 4) is an example of that procedure. The replacement solar array, STSA-2, consists of two wings which, during the launch, are in a stowed (rolled-up) configuration and mounted on a solar array carrier. The carrier is a stiff structure with shock dampers to protect the array during launch and landing. It has two permanent locations to store STSA-2 during launch and then the original solar array, STSA-1, during landing. It also has a temporary stowage location where one wing can be placed during the change-out.

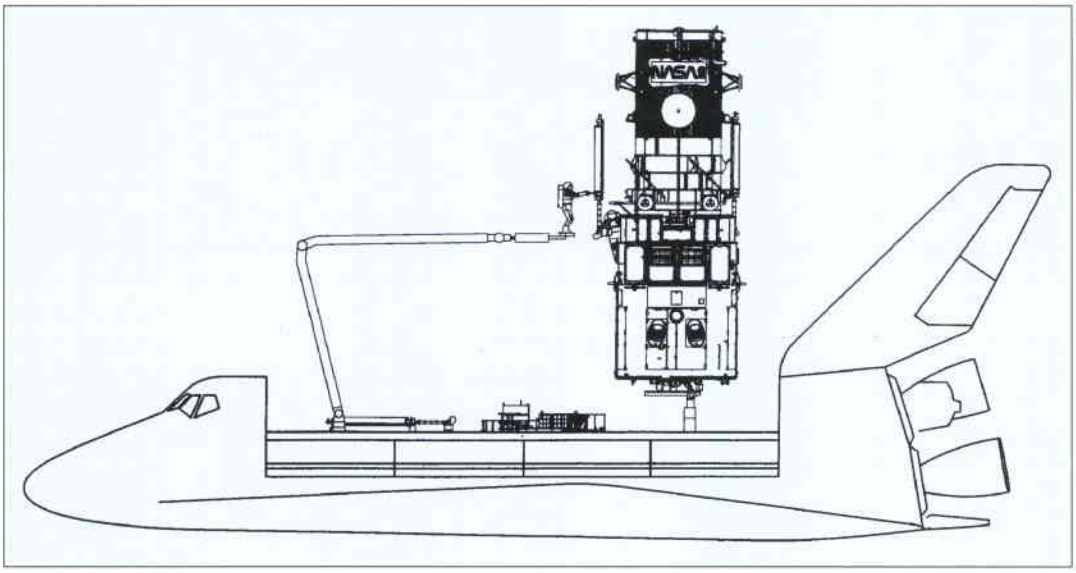
On the day before the exchange of STSA-1 and STSA-2, the astronauts make preliminary preparations on the solar array carrier and the STSA-1 solar array blankets are then retracted by ground command.

On the day of the exchange, immediately before the EVA starts, the Primary Deployment Mechanism, which holds each wing of the solar array away from the body of the HST, is also retracted so that the wings are lying close to the HST body. During the EVA, one member of the astronaut team is on the RMS arm, held in a Manipulator Foot Restraint, while Claude Nicollier guides the arm, placing the astronaut in the optimum working position. The second member of the team uses hand holds which are placed at appropriate locations on the HST.

They then perform the change-out:

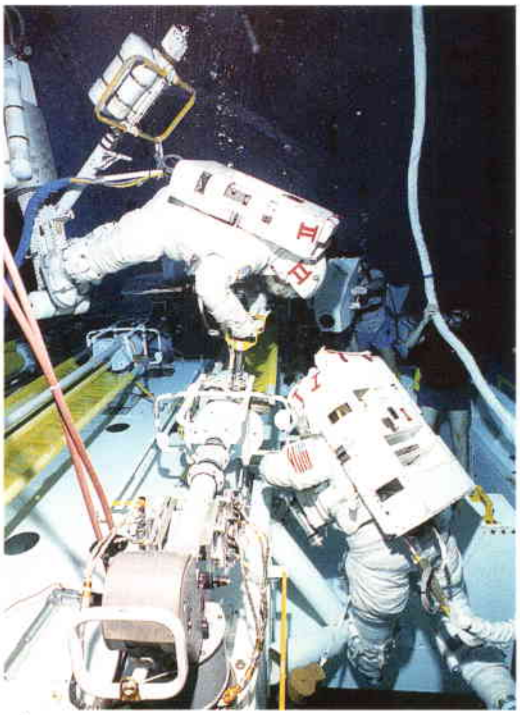
- Together, they detach the first wing of STSA-1 from the HST (Fig. 4a, b) and transport it to the solar array carrier (Fig. 4c), where they install it in the temporary stowage location (Fig. 4d).
- They then take the first STSA-2 wing and install it on the HST in the vacant location.
- They remove the second STSA-1 wing from the HST and place it on the carrier in the space vacated by the first STSA-2 wing.
- They transport and install the second STSA-2 wing on the HST.
- Finally, they move the STSA-1 wing from the temporary stowage position on the carrier to the permanent position occupied previously by the second STSA-2 wing. In this way, the HST is left with a new solar array and the original is ready to be brought back to Earth for post-flight examination.

This exchange is expected to take just over five hours of the maximum, nominal permitted EVA time of six hours. This leaves a margin for problem resolution or the



a

b



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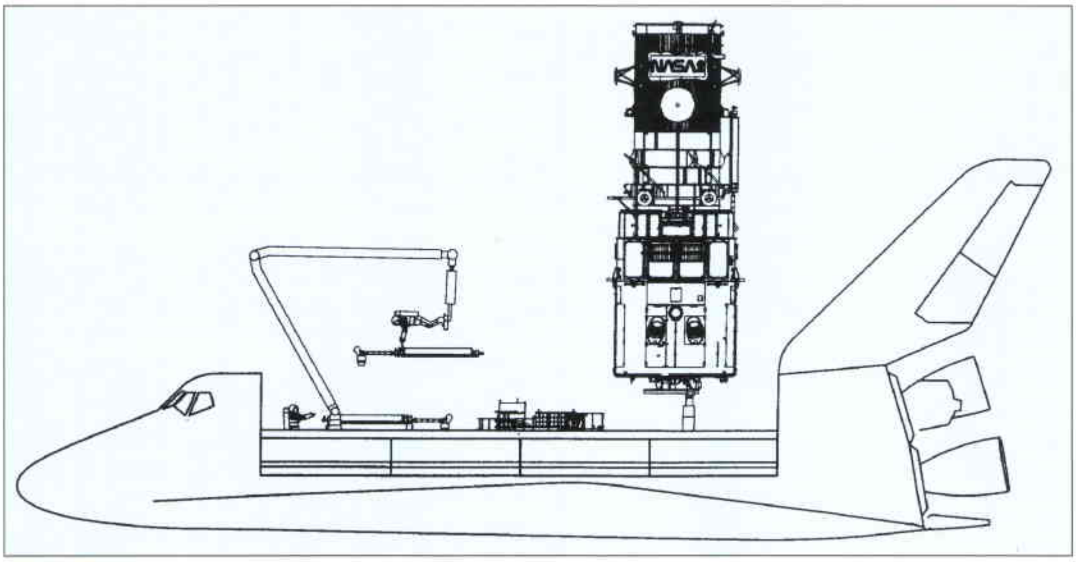

c

Figure 4. The change-out of the solar array

a. The astronauts detach the solar array from the HST. One astronaut is held on the end of the arm of the Remote Manipulator System, while the other astronaut uses foot restraints on the side of the HST.

b. The astronauts practise removing the solar array from the HST mock-up in the Neutral Buoyancy Simulator at MSFC

c. The astronauts place the STSA-1 array on the solar array carrier in the cargo bay for return to Earth

d. The astronauts install the solar array in storage brackets on the solar array carrier, during testing in the Neutral Buoyancy Simulator

installation of one of the secondary payload items. Following the installation of the solar arrays and before the end of the EVA, a short aliveness test is performed to ensure that all connections have been made correctly. However, full testing is only possible after the deployment of the solar arrays during the last EVA.

Ground support to the HST Servicing Mission

During the mission, most public attention is focussed on the activities in the Shuttle and on the EVAs. However, in order to support those activities, an army of personnel is deployed on the ground 24-hours a day while the shuttle is in orbit. Because of the complexity of the mission, it is difficult to estimate the number accurately but there are several thousand engineers on the ground supporting the seven astronauts in the Shuttle.

The mission is run from the Mission Control Center at Johnson Space Center (JSC) in Houston. The main control room is staffed, as it is for every Shuttle mission, with the STS team that organises the Shuttle itself and the crew activities. This team includes an astronaut in the control room who acts as the communication link with the crew on board Endeavour.

HST teams both from Goddard Space Flight Center (GSFC) and from the various suppliers of hardware to be installed in the HST, such as ESA, are also at JSC. They do not sit in the main control room at JSC, but are located in two other areas: the Customer Support Room (CSR) where most of the management and leading mission controllers sit, and the Payload Operations Control Center (POCC) where the support engineers monitor the health of the HST and advise the management of JSC and GSFC if anomalies occur.

The Space Telescope Operations Control Center (STOCC) at GSFC controls the HST, including the detailed monitoring and all commanding of the HST. During an EVA, the STOCC team commands the HST when so requested by the teams at JSC. During Shuttle crew sleep periods, the team also carries out more intensive check-outs of equipment newly installed in the HST.

Training for the HST Servicing Mission

For a mission as complex as that to be undertaken in December, intensive training is necessary. It not only ensures that the mission runs smoothly, but also allows the duration of each activity to be determined to ensure that EVA time is not wasted, either by running out of time on any day or by having insufficient activities planned to fill each EVA day. As the JSC Mission Director constantly reminds everyone, EVA time is the most valuable consumable and must be filled with 'useful work'.

In the initial training, the Shuttle crew and the ground crew train separately. Later, they join forces in Joint Integrated Simulations.

The crew training specific to the HST Mission concentrates on the feasibility and timing of the tasks that they must perform during the Mission. Considerable time is spent in two large water tanks at Marshall Space Flight Center (MSFC) and at JSC, simulating working in microgravity. By means of weights attached to them, the astronauts are suspended in the water in an approximation of weightlessness and they rehearse the activities that they will carry out during the mission. With the experience that it has gained over the past two decades, NASA can deduce from this the feasibility of each task and the time required to perform it. The EVA crew has also visited the facilities where hardware for the mission has been manufactured, and the crewmembers practise using the various tools they will use to install the hardware during an EVA (Fig. 5). These visits are used to decide on possible scenarios for installation and to suggest modifications, which can be quite minor (such as a change in the colour of an indicator) but which will make their task in orbit less complicated.

The training of the ground crew is quite different. The Shuttle ground team has much experience (this will be STS-61) so they can build their mission-generic training on a basis of solid knowledge. The HST-related tasks, however, are unique and must be rehearsed fully to ensure that the ground crew does not leave the astronauts idle during an EVA. Initially, the GSFC STOCC team carried out simulations to ensure that everybody knows what to do and how to do it for every minute of the mission. This included not only nominal cases representing a faultless mission, but also a number of anomaly or contingency cases where something has gone wrong. As part of this exercise, documents such as the Flight Rules, Contingency Procedures, and Fault Isolation Procedures, which attempt to predict what can go wrong and the optimum course of action to correct it, were drafted. This documentation has been turned into a library which will be at the console of each key participant in the ground crew during the mission.

Following this period of separate training, the ground crews at GSFC and JSC join forces with the astronauts to simulate the whole 11-day mission through Joint Integrated Simulations (JIS). During these exercises, a separate, but knowledgeable, JIS team invent anomalies in order to train the whole team how to deal with them. For each JIS, all personnel must be at the location they will occupy during the mission, including the shifts for 24-hour per day operation. The library of rules which was developed during the earlier simulations becomes the reference for each participant but the JIS team is adept at inventing new problems. Often the management 'Tiger Teams' must convene in order to decide the best strategy. Although this may appear to be like playing 'war games', the simulations are taken very seriously and are very important in establishing processes and group dynamics.

An additional complication is the fact that during an average shuttle mission there may be more than 20 voice communication loops operating at the same time, and the key operators and management may have to listen to as many as five or six simultaneously. Another purpose of the JIS is therefore to enable the operators and managers to identify the voices on the various loops and to learn the difficult art of listening to several conversations at the same time.

Post-flight investigations

Another major objective of the mission will not be achieved until after the mission has returned to Earth. The on-board equipment has been in orbit for three and a half years and the units that have been replaced will be transported back to Earth at the end of the mission. There will therefore be a rare opportunity to make detailed examinations of the results of such a long exposure to the harsh environment of space in relatively low Earth orbits and to examine first hand the damage caused, for example, by the effects of atomic oxygen and ultraviolet radiation.

The returned solar arrays will be brought back to Europe where intensive investigations will be made not only into the way in which the solar cells themselves have deteriorated over the years but also into the wear of mechanisms, the effect upon the structures, and the damage caused by impacts of micro-meteorites and space debris upon the deployed array area of over 60 m^2. This investigation, to be carried out at ESTEC and in industry, is expected to last for more than a year and to add considerably to the store of knowledge about the effects of long-term exposure in space.

Figure. 5. ESA astronaut Claude Nicollier practises operating the equipment that will be used during the mission to exchange the solar arrays. Kathy Thornton, another crewmember, looks on.

Conclusion

There is no doubt that the first HST Servicing Mission will be a complex and demanding task. It is based, however, on a concept that has been in place for more than 15 years and therefore the approach to the tasks that need to be carried out is anything but ad hoc. Each activity has been thoroughly thought out and well rehearsed, and there is every reason to believe that the mission will be very successful.

This mission will also form the baseline upon which further servicing missions will be planned and executed, thus prolonging the life of the HST as a state-of-the-art space observatory well into the next century.

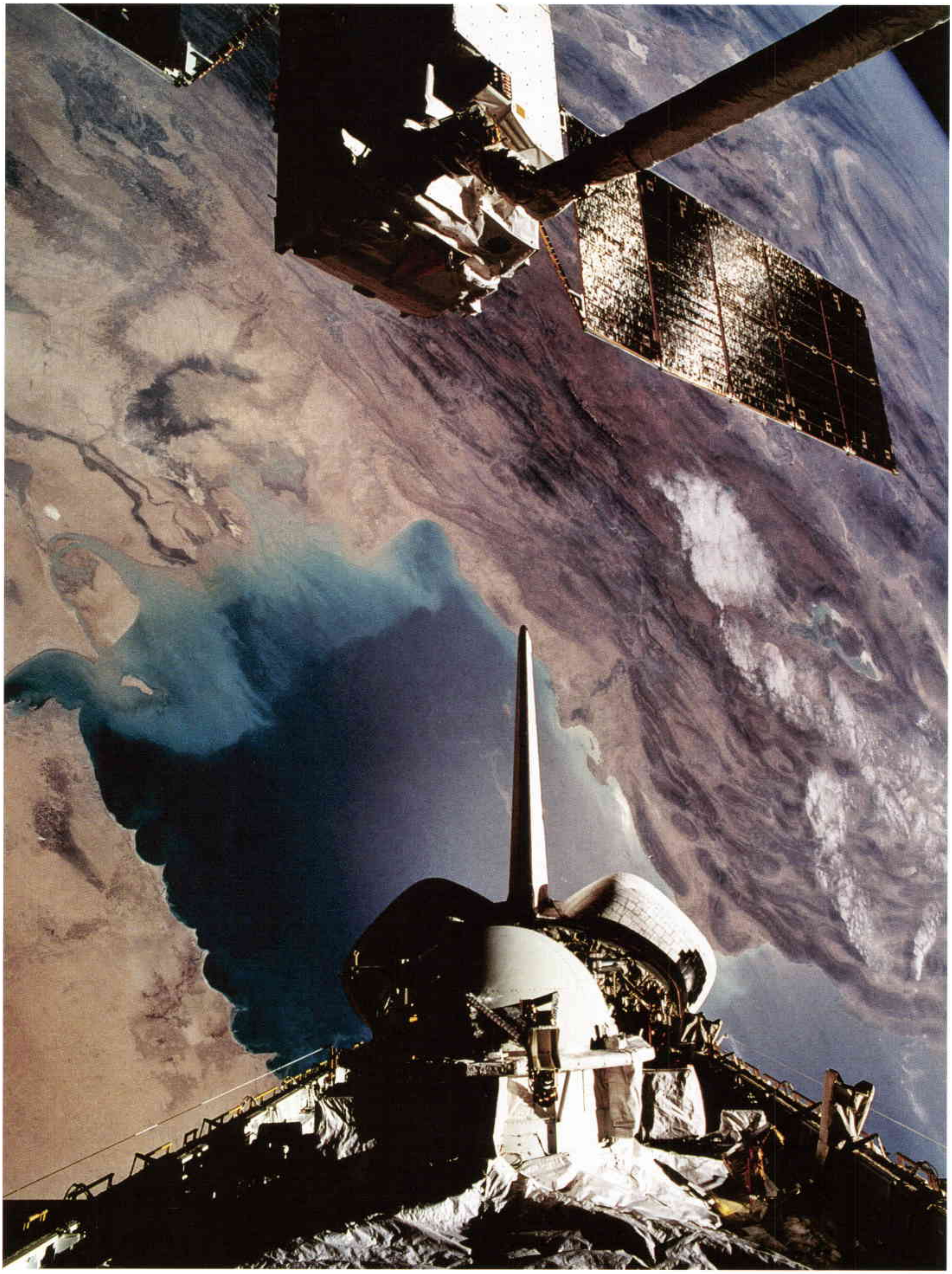

Figure 1. Eureca attached to the Remote Manipulator System (RMS) of Space Shuttle 'Atlantis', after solar-panel deployment

The Joint ESA–NASA Operations for Eureca's Deployment and Retrieval

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The first flight of the European Retrievable Carrier was a complete success both from the point of view of the payload science operations and of the demonstration of the concept of operating a retrievable automated platform in space for long periods. The more complicated mission operations and greater manpower invested in utilising the Space Shuttle for Eureca's deployment and retrieval were compensated by this success and by the invaluable experience that ESOC gained in conducting complex inter-agency operations in the manned space environment.

Introduction

The European Retrievable Carrier (Eureca) is a reusable multipurpose space platform designed to be launched and retrieved up to five times by the Space Shuttle. One of the Carrier's main characteristics is the low-acceleration environment that it offers which is ideal for microgravity science. The first mission carried a core payload of five facilities for microgravity experiments, but also a number of additional science payloads for space and Earth-atmosphere observation, technological experiments, and a package for inter-orbit communications.

The use of the Space Shuttle for Eureca's deployment and retrieval operations imposed constraints on the Carrier's orbital inclination and consequently on the choice of ground stations. The latter had to be at latitudes compatible with the Shuttle's 28.5° inclination orbit in order to obtain a favourable sequence of ground-station passes. The Carrier and the ground segment also had to be designed to cope optimally with the differences between the routine phase of the mission and the common operations phases with the NASA system. In particular, two different communications systems had to be established for the Eureca–Shuttle–ground and Eureca–ground-station links. The type of operations was also completely different in the two cases: short contact periods and mainly offline activities of command-file preparation and telemetry dumping and analysis characterised the routine phase of payload operations; for the deployment and retrieval phases, operations consisted of critical real-time activities with almost continuous coverage via the NASA space data-relay system (TDRSS).

The first Eureca mission achieved almost seven months of microgravity operations, one month longer than planned. An additional four months in orbit were available to the rest of the payload for non-microgravity science. About 1000 commands were uplinked and executed on-board the spacecraft every day to control the complex operations of the Carrier subsystems and the fifteen payload instruments.

This article focusses on the joint operations conducted by ESA and NASA for Eureca's deployment and retrieval.

Mission definition and preparation

Preparations for the joint operations and the definition of the necessary procedures were conducted in the framework of standard NASA Payload Operations Working Group (POWG) meetings, held at Johnson Space Center (JSC) in Houston. These meetings, which started about three years prior to the mission, were attended by a team of operations engineers from ESTEC, ESOC and Eureca's industrial manufacturer (ERNO), who were supported by subsystem design engineers specialised in such areas as thermal and attitude and orbit control. NASA participation in these POWG meetings included a dedicated Eureca Operations Team, led by the Eureca Payload Officer, the Flight Director and other key mission controllers. The Space Shuttle crews also participated in many of the meetings, particularly for the definition of the detailed operational back-up procedures to be conducted on-board.

The standard approach for Shuttle payload operations was applied to Eureca.

This involves the preparation of a number of documents and review cycles for the operational documentation, repeated for each Shuttle mission. From NASA's point of view, Eureca's deployment and retrieval were two different missions, although the commonality with the deployment mission procedures could be used to reduce the effort involved in preparing for the retrieval. On the other hand, the two missions – involving two different flight crews – had completely opposite objectives, which had to be reflected in the contingency recovery procedures in particular, with very different reactions to the same failure case depending on whether the failure had to be overcome during the deployment or during the retrieval phase.

The retrieval mission had the additional operational complication of the rendezvous activities, which involved much greater participation by ESOC's flight-dynamics experts in the discussions with NASA. The different strategies discussed for achieving the rendezvous and how the activity was finally successfully carried out are the subject of the companion article in this issue of the Bulletin.

The final version of the operational documentation was the subject of an intensive review exercise by all parties during the Flight Operations Review (FOR). This review was conducted separately for the deployment and retrieval missions, about six months before each flight. The resulting updated documentation formed the basis of the internal ESOC and NASA training and simulation programme, culminating in the Joint Integrated Simulations (JIS) conducted with the full participation of the two Control Centres, ESOC and JSC.

In parallel with the finalisation of NASA's documentation, the ESOC Flight Operations Plan was also finalised. Internal ESOC simulations of the critical mission phases started for both deployment and retrieval about six months before the Shuttle launch, involving ESTEC Project and Industry personnel in a consultancy support function.

The NASA norm of three JIS sessions per Shuttle payload was initially planned for Eureca. The complicated nature of the procedures to be exercised suggested an extension of the joint simulations programme for the deployment mission in particular, including more official JIS sessions and the participation of ESOC in internal JSC general-purpose simulations. JSC personnel also travelled to Germany to participate in some ESOC internal simulations.

Additional flight-dynamics-dedicated simulations were arranged for the retrieval mission between the experts of the two agencies. NASA-JSC flight-dynamics personnel were also present at ESOC, in a supporting role, during the final critical manoeuvring and retrieval phases of the mission.

Overall, the ESOC simulation programme involved about 600 h for the deployment and more than 100 h for the retrieval mission, covering all nominal and critical failure mode simulations. Although a less intensive preparation phase was needed for the retrieval mission, thanks to the experience gained in preparing for and conducting the deployment operations and the many common aspects of the two missions, the overall workload for the ESA operations personnel was extremely high. During the final phase of the Eureca flight in particular, routine mission-control activities and preparation activities for the retrieval phase, including documentation review, updating, participation in joint NASA–ESA meetings and teleconferences, and simulations, had to be carried out in parallel by the same people.

Operational setup and responsibilities

Both the deployment and retrieval missions involved parallel operations at the two main control centres, NASA/JSC in Houston and ESOC in Darmstadt. At ESOC, a typical Mission Control Team was in charge of the Eureca operations. Under the central responsibility of the Flight Operations Director, the different areas of operations were led by the Spacecraft Operations Manager (SOM), the Ground Operations Manager and the Flight Dynamics Coordinator. The Eureca Project Manager, with his project support team of ESTEC and Industry experts, was also located at ESOC.

For the retrieval mission, an additional position, that of Safety Officer, was created at ESOC to directly and continuously monitor the Shuttle crew-safety-related status of Eureca, particularly during the final approach phases, when the deactivation steps included the gradual re-establishing of safety inhibits for the critical Eureca subsystems.

A small group of ESTEC project experts was located in a Shuttle-payload-dedicated 'Customer Support Room' at JSC, their main task being that of directly interfacing with the

NASA operations community in the unlikely event of a loss of communications with ESOC, and to provide Eureca knowledge on the spot for possible detailed discussions in case of the need for Extra-Vehicular Activity (EVA) from the Shuttle.

Seven dedicated voice loops were operated in parallel between Houston and Darmstadt, to provide separate channels for operational communications at various levels.

The responsibilities for operations were clearly divided such that JSC was in charge of the Shuttle activities and ESOC was responsible for the Eureca activities. Naturally, close coordination was required for most of the respective activities, and both centres were working on the basis of a common set of documents and timelines.

Apart from a few initial activation steps, which had to be carried out via switches on-board the Shuttle when Eureca was connected to the Shuttle umbilical, and all the robotic-arm movements and Shuttle manoeuvres, all Eureca-related activities were under ESOC's control via a telemetry and telecommand link.

Crew safety

One of the key issues to be considered for a spacecraft to be carried onboard the Space Shuttle is crew safety, in terms of both the spacecraft's design and its operation. Special design criteria have to be applied wherever there is a potential crew health hazard, leading in some cases to the implementation of three independent inhibit levels to guarantee double fault tolerance.

All potentially hazardous areas of Eureca's operations (accidental rupture of pressurised system components, hydrazine leaks, etc.) were therefore analysed in great detail before the mission and the necessary passive or active safety measures implemented. A sophisticated command protection mechanism was also implemented at ESOC, to prevent potentially dangerous commands from being inadvertently uplinked.

To avoid potentially hazardous commands being executed autonomously by Eureca's onboard software and endangering the crew, part of the Carrier's onboard software was disabled, including its ability to execute time-tagged commands, whenever Eureca was in close proximity to the Shuttle (inside the so-called 'safety distance').

For those safety-related areas that could be affected by the operations themselves, such as the status of the hydrazine propulsion system, special flight safety rules had to be followed by the operations team. Specific rules had been worked out jointly by ESA and NASA which described the conditions under which Eureca was to be considered 'hazardous' and specific courses of action to be followed if such a condition arose within the safety distance.

During proximity operations, the safety status of the complete Carrier was reported to NASA/JSC by the ESOC Flight Director at least once per orbit (i.e. every 1.5 h).

Eureca's deployment

Following a smooth countdown, the Space Shuttle 'Atlantis' lifted-off at 13:56:48 UTC on 31 July 1992 and successfully carried Eureca into the deployment orbit. During this launch phase, Eureca was completely inactive until 01:58 MET (Mission Elapsed Time), shortly after the opening of the cargo-bay doors, when the thermal-control unit was activated by the ESA astronaut, Claude Nicollier, using Shuttle power flowing via an umbilical connection to the Carrier. Thermal monitoring was available to ESOC from that moment on, and the 'blue shift' team onboard Atlantis could go to sleep.

The deployment day started some 10 h later, when astronaut Nicollier checked out the Shuttle's Remote Manipulator System (RMS) and started the sequence of events needed to lift Eureca out of the cargo bay. Eureca's own power was activated via switches located inside the Shuttle's aft crew compartment. The payload retention latches that were keeping Eureca connected to the Shuttle were opened and the umbilical connection removed, so that the Carrier could be lifted with the robotic arm into an initial position known as 'low hover'.

In parallel, ESOC sent ground commands to start the long Eureca activation sequence, which was planned to lead to the Carrier's release from the Shuttle about 6 h later. This sequence included activation of all the Carrier's subsystems, deployment of the solar panels and the antennas, and testing of the coarse Sun acquisition sensors with the help of re-orientation manoeuvres executed as a combination of RMS movements and Shuttle attitude changes.

The first telecommand for spacecraft activation was successfully executed at 01:41 UTC on 1 August, and activities proceeded smoothly until the main Eureca

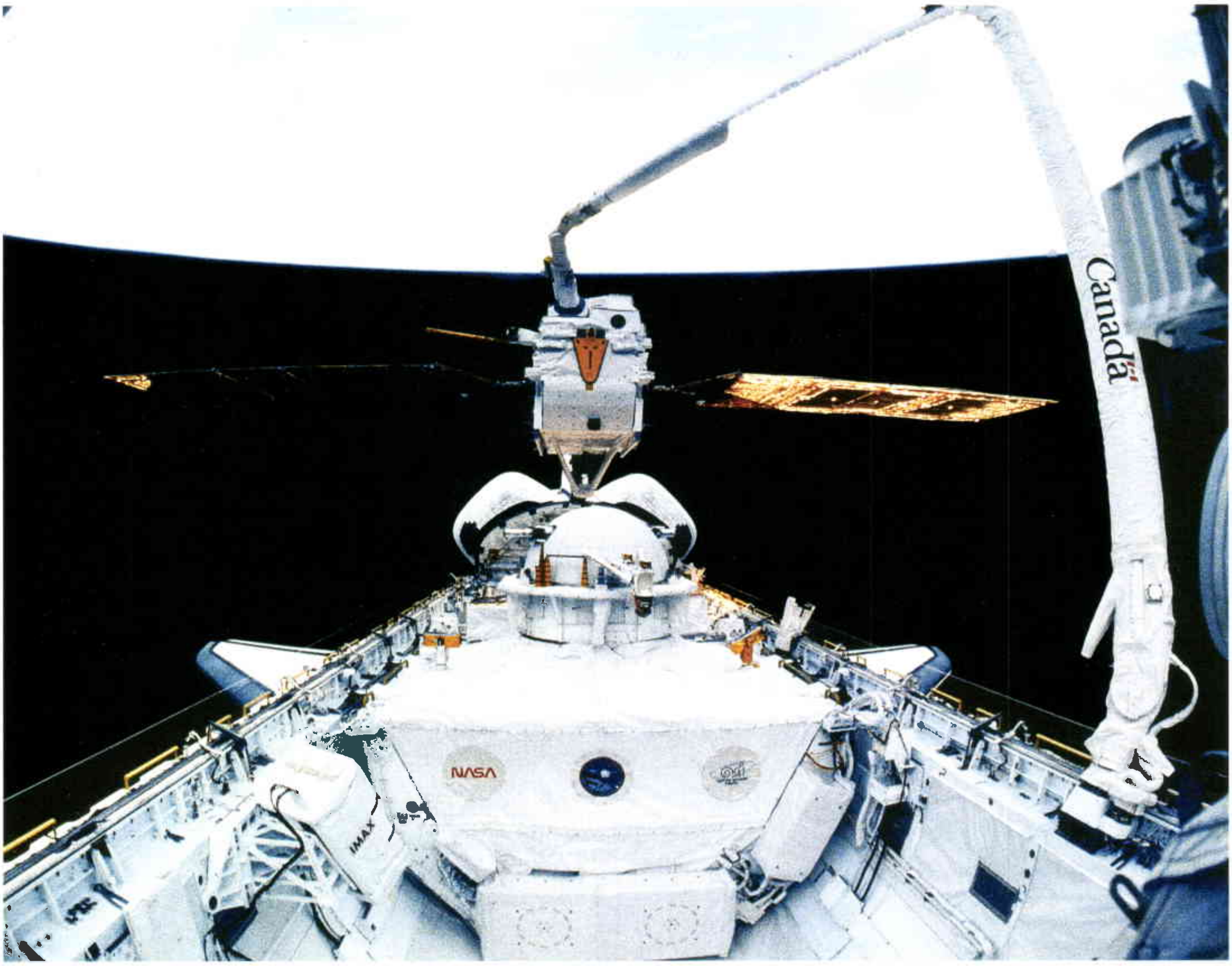

Figure 2. Eureca in its 'overnight parking position' above the cargo bay of 'Atlantis'

computer was activated: at that time, large gaps in the telemetry link to the Shuttle, and therefore to the ground, were experienced.

Investigation of this completely unexpected problem involved execution under time pressure of complex redundancy switching of practically all the Eureca and Shuttle units involved in the telemetry chain, but this allowed no clear conclusions regarding the source of the problem. During this trouble-shooting activity, two further communications problems occurred: one on-board Eureca between the data-handling subsystem and the thermal and attitude and orbit control subsystems, and one on the ground between the NASA Control Centre in Houston and ESOC. The ground problem was identified as being due to an unsolicited routing of data previously recorded on-board the Shuttle, and was easily solved, albeit after several hours, by requesting NASA to stop the data transfer.

The on-board malfunction was much more difficult to resolve, as it involved the development of a complicated operational work-around solution by reconfiguring the on-board data links from the two critical thermal and attitude-control subsystems by means of an on-board software patch, and in parallel executing a sequence of commands to recover the data transfer every time the problem occurred. The manual recovery procedure designed during this phase allowed the data link to be re-established just a few minutes of the problem occurring, and was used for several weeks during the initial phase of the mission until on-board software work-around solutions could be implemented.

In this situation, the most critical issue was the deployment of Eureca's solar panels, which had to be performed with a maximum of 1.5 h delay to avoid complete depletion of the Carrier's batteries and thereby ensure continuation of the mission. To complete the activation steps required to start the solar-panel deployment, it was decided to try commanding Eureca via ESA ground stations, something that was never contemplated before the mission started. Two passes over Kourou (French Guiana) and Maspalomas (Canary Islands) stations in close succession were available at a favourable moment at the beginning of the orbital Sun phase. However, just prior to the start of the Kourou pass, the Maspalomas antenna experienced a problem which made it temporarily unavailable. This reduced the available commanding time to the 7 min of the Kourou pass only.

The Kourou ground-station pass during the 10th orbit became the pass that saved the entire mission. The on-board data-handling subsystem was successfully re-configured to support the solar-panel deployment, which was executed at 05:24 UTC – about 1 h later than planned – using the Shuttle telecommand link.

A memorable feature of this mission for the ESOC team was being able to actually watch the slow solar-array deployment, with Eureca illuminated by the Sun and with the Earth in the background. This was the first time for them that the effect of a telecommand had been observed directly, rather than being verified via the less exciting medium of reviewing numbers and plots on a computer display!

Another critical aspect of these hours was the intermittent availability of temperature data from the Eureca thermal-control unit, caused by the problem with the data-handling subsystem and the need for manual recovery each time. On one occasion, almost two hours passed without Eureca thermal data, when the interface problem happened to coincide with a planned spacecraft reconfiguration, which temporarily prevented commanding to recover the thermal-control interface.

Once the Carrier's power supply had been secured, to the considerable relief of those in the Main Control Room at ESOC, the mission could continue and more time was then available for solving the remaining complications. It was decided to use the planned back-up opportunity to deploy Eureca the next day, allowing ESOC and NASA time to continue their trouble-shooting activities overnight. Additional activation operations, including the deployment of Eureca's S-band antennas, were carried out as far as possible before configuring the Carrier for 'overnight parking' attached to the RMS.

This proved to be a good decision since, a few hours later, the suspected source of the problem, an incompatibility between some Eureca telemetry packets and the Shuttle's communication system, which had never been apparent during ground testing, was confirmed. A contingency plan was developed at ESOC during the night that would allow the following day's deployment activities to be executed only via ESA ground stations, with which the telemetry and telecommand links had been proved to work flawlessly during the first day.

The contingency timeline developed during the night was executed on 2 August, and Eureca was successfully deployed at 07:07 UTC during orbit 27. Extensive use of the ESA stations continued, although the new telemetry modes started after Eureca's release from Atlantis's robotic arm seemed to cause fewer problems with the link to the Shuttle too. The Sun-acquisition and Earth-acquisition manoeuvres were executed according to the new timeline, but the orbit-transfer manoeuvre, started as planned at 12:30 UTC, had to be interrupted 6 min into the burn due to a growing deviation from the Platform's mandatory Earth-pointing attitude.

At this point, the Shuttle was still in the vicinity of Eureca, but it was quickly decided that any attempt to retrieve it for further trouble-shooting would be risky and would not have improved the chances of success. The NASA support was therefore terminated, Atlantis left the deployment orbit, and Eureca was parked in the intermediate orbit that had been reached after the manoeuvre abort, awaiting ground investigations to find a solution.

The attitude problem was identified, after a round-the-clock investigation at ESOC lasting three days, as being due to a parameter order inversion in two ground computers, which resulted in an incorrect parameter table being uplinked to the attitude-control software. The error was corrected and the orbit manoeuvres successfully executed on 6 and 7 August to carry Eureca into its final circular operating orbit at 502 km altitude.

The communication problem with NASA was later reproduced in NASA test equipment using data generated at ESOC by the high-fidelity Eureca software simulator. This proved that some Eureca extended telemetry packets were incompatible with the Shuttle communications system and therefore caused loss of telemetry bit synchronisation. An operational work-around solution was designed for the retrieval mission that proved completely successful during the actual operations.

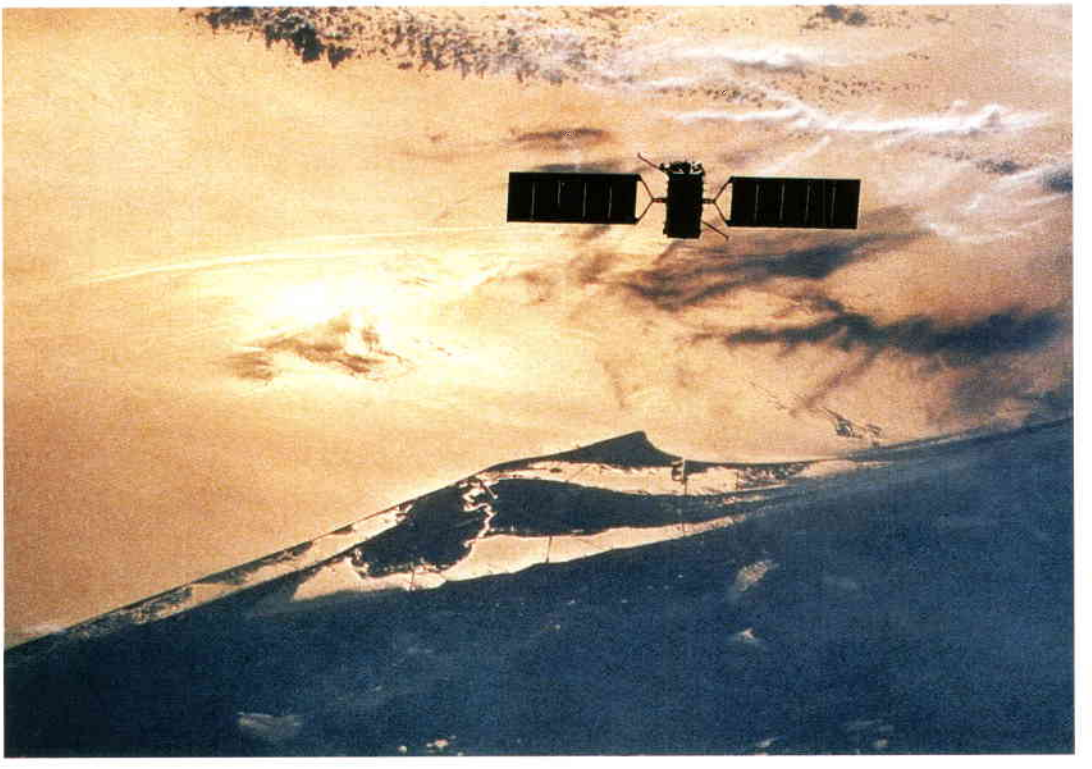

Figure 3. Eureca over Kennedy Space Center shortly after its release from 'Atlantis'

The Eureca deployment operations were successful despite an unfortunate multiple-failure scenario that came very close to jeopardising the entire mission. In design methodology, a double-failure scenario is considered to have an extremely low probability of occurrence. The Eureca deployment mission showed that, taking both the space and the ground segments on the ESA and NASA sides, four or five failure conditions can actually develop in parallel, making the chances of success both very small and highly dependent on the ability of the mission controllers to react in the best possible way to unexpected situations.

Eureca's retrieval

The retrieval operations started on 20 May 1993, when the first orbit-transfer manoeuvre to bring the spacecraft into the rendezvous orbit was carried out. After a number of orbit adjustments, a stable orbit was reached on 9 June, which would keep the evolution of the key orbital elements – altitude, eccentricity and argument of latitude – within the thresholds required by NASA for a period of a few weeks, to cope with possible Shuttle launch delays.

In the nominal case, no further change in the Eureca orbit was planned, it being the Shuttle's responsibility to reach the rendezvous orbit with a combination of manoeuvres after injection into its initial orbit. However, the possibility of a problem occurring with the Shuttle during the ascent phase, resulting in an orbit significantly lower than nominal, had also to be taken into account in the retrieval preparation. Such a situation could have forced Eureca to execute a large orbit manoeuvre within 4 h after the Shuttle's launch, to dramatically reduce the Carrier's altitude and hence also the differential phasing of the two vehicles. Contingency procedures and related sequences of time-tagged commands were prepared before the launch for six different Shuttle underspeed scenarios.

In the event, none of the contingency scenarios was needed as Space Shuttle 'Endeavour' lifted off perfectly at the second attempt on 21 June at 13:07:22 UTC, just 22 s after the opening of the launch window (the first launch attempt having been cancelled the previous day due to bad weather conditions), and achieved its nominal orbit, from which all of the planned rendezvous manoeuvres could be successfully executed (despite a last-minute postponement of one of the manoeuvres to avoid risk of a potential collision with an orbiting expended rocket stage!).

Meanwhile, Eureca continued to function nominally and some of its payloads were still being operated even after the Shuttle's launch, including the Inter-Orbit Communications (IOC) technology payload and the Wide-Angle Gamma-ray Telescope (WATCH). The final deactivation of the safety-critical hydrazine propellant system took place on 23 June, one day before the deactivation of the rest of the spacecraft, to allow ESOC to monitor the system's internal pressures in order to detect any potentially dangerous leaks.

Retrieval was planned for 24 June. While the Shuttle was executing its last approach manoeuvres, ESOC prepared a sequence of time-tagged commands to be loaded on-board Eureca into the so-called 'master schedule' for automatic execution of all the critical activities required to configure the spacecraft into a 'ready-for-grapple' status. The command schedule was uplinked during a combined pair of passes over the Kourou and Maspalomas ground stations at 07:55 UTC. At this time, the Shuttle was still more than 100 km away, but closing steadily.

The most important of the time-tagged retrieval activities was the retraction of Eureca's solar panels, an activity that was also subject to a number of severe and conflicting time constraints. It had to be executed in the absence of sunlight, in that part of the orbit when the Carrier was in the Earth's shadow, to avoid the mechanisms being disturbed by thermal distortion of the large panels. It had also to be executed while the Shuttle was still relatively far from Eureca (more than 1000 ft), to avoid the plume from the Shuttle's manoeuvring jets disturbing the Carrier's attitude by impacting on the extended panels. Finally, it had to take place as close as possible to the final deactivation of the spacecraft, due to the limited amount of energy storage provided by Eureca's four batteries.

The point in the retrieval sequence chosen for solar-panel retraction was the start of the last Earth-shadowing period before the nominal 'grapple time', i.e. the time at which Endeavour's robotic arm would 'capture' Eureca. It was predicted that a maximum of 196 min would be available for the retrieval activities from the moment the solar panels were retracted until the moment that the spacecraft was grappled with the Shuttle's arm. Thereafter, only a quick deactivation would be possible before depletion of the available energy reserves in the batteries.

Figure 4. Eureca shortly after being 'grappled' by Space Shuttle 'Endeavour's' robotic arm

The nominal duration for the retrieval activities was about 100 min, but any delay in Eureca's deactivation or the Shuttle's approach sequence could have reduced the margin significantly. In the event of large delays, ESOC would have had the possibility to execute a solar panel re-deployment, but no later than 169 min after the start of retraction, for power reasons.

It was planned that the direct communications link between Eureca and the Shuttle would be established as soon during the final approach phase as the distance between the two vehicles would allow. At 08:38 UTC, Endeavour's crew successfully activated the telemetry link from a distance of about 78 km. Continuous real-time contact with Eureca, with the exception of two small gaps every orbit, was available from that moment on, throughout the entire retrieval phase, via the NASA data-relay satellite system and the NASCOM network to which ESOC was connected. This moment was particularly critical since it was the first time, after all the communications problems experienced during the deployment mission, that the theories that explained the behaviour and the workaround solutions designed in the meantime in the Eureca telemetry configuration could be verified in practice. The excellent performance of the link during the entire retrieval phase confirmed the simulation results and the validity of the solutions implemented.

At 11:27 UTC, the Shuttle performed the last correction manoeuvre – the so-called 'TI burn' – which put it on a trajectory that would lead to it intercepting Eureca within one revolution. In the meantime, the time-tagged commands previously loaded on-board Eureca automatically executed an attitude manoeuvre to align the Carrier's x-axis perpendicular to the orbital plane. This attitude improved the approach conditions for the Shuttle if retraction of Eureca's solar panels had proved problematical.

Solar-panel retraction began at 12:06 and was successfully completed at 12:12 UTC. An unambiguous telemetry confirmation of the retraction was required by the ESOC flight controllers before proceeding with the manually commanded latching operation; the fact that the Carrier was still several kilometres from Endeavour, and the absence of sunlight, made it impractical to attempt an optical verification by the Shuttle crew. Once retraction was confirmed, the latching was commanded from the ground and was confirmed for both wings by ESOC at 12:38 UTC, when the 'GO' for the final Shuttle approach was given to the NASA flight controllers.

The only remaining activity prior to 'grapple' by the Shuttle's robotic arm, which was scheduled for 13:44 UTC, was the folding of the two radio-frequency antennas. This operation was planned to be manually commanded from the ground in the quiet commanding phase between the end of the solar-panel retraction in eclipse and the final grapple activities. The first antenna to be retracted was antenna number 2, since the other one was still being used to communicate with Endeavour and the ground. The commands were executed at 13:00 UTC, but no final telemetry confirmation of complete retraction, which should have come from a microswitch at the end of the boom movement, was received. The antenna boom had apparently stopped at an angle of only a few degrees from the end-stop position.

While troubleshooting started immediately, it was decided to continue with the nominal plan and to attempt retraction of antenna number 1, which was possible by then without disturbing communications with the Shuttle because the two vehicles were now only a few hundred feet apart. Unfortunately, this antenna also failed to complete its retraction, in exactly the same way.

The problem was diagnosed as being caused by deformation of the multi-layer insulation installed on the Carrier structure in the area where the antenna booms were supposed to be retracted. Due to the proximity to the Shuttle and the critical approach operations in progress, it was decided to postpone any new antenna retraction attempt until the post-grapple phase.

The camera on the Shuttle's robotic arm provided excellent pictures of Eureca while Endeavour's Commander, Ron Grabe, was manoeuvring his craft to within about 10 m. The robotic arm was then activated and the rigid grapple achieved at 13:54 UTC. Eureca looked very stable on the television pictures, and the final approach and grapple manoeuvres proceeded extremely smoothly. Subsequent detailed analysis of the attitude and orbit control telemetry showed, however, that the Carrier's small nitrogen thrusters were working hard during this approach phase to counteract the forces resulting from the impingement of the Shuttle's thruster plumes.

After Eureca's capture, the nominal activities continued with rapid deactivation of its attitude and orbit control subsystem. Attempts at trouble-shooting on the antenna-retraction problem did not succeed, and the decision was taken to adopt the pre-mission contingency plan which involved leaving the Carrier attached to the robotic arm overnight and keeping it 'alive' with energy from one of the two already-folded solar panels, which could still be pointed at the Sun. Two Shuttle astronauts were scheduled to perform an EVA (Extra Vehicular Activity) training sortie the next day, during which one of them could have pushed the antenna boom home whilst ESOC commanded the mechanical latching.

This plan had to be modified, however, because one of the prerequisites, the provision of Shuttle power via the robotic arm for Eureca thermal control, could not be achieved. This forced a decision to completely deactivate Eureca, berth it and latch it in the cargo-bay, so that the remote umbilical could be connected to provide Shuttle power. The disadvantage of this solution was that there was no guarantee that telecommands to re-activate Eureca the next day to support the contingency EVA would work with the Carrier down in the cargo-bay. The advantage was that, with Eureca latched in the bay, the Shuttle's robotic arm could be used to support the astronaut during EVA.

The berthing of Eureca was subsequently completed at 16:28 UTC on 24 June, and the umbilical power for thermal control was activated 16 min later. The first temperature measurements confirmed that all safety-critical temperatures were still well within limits. Once again a time-critical situation had been successfully mastered and Eureca was safe in the Shuttle's cargo-bay.

The following night there was intense re-planning activity both at ESOC and at JSC to define and agree the new combined procedures for the antenna-retraction EVA activities. As this two-failure condition had never been foreseen, no detailed procedures had been prepared in advance. The two EVA astronauts, David Low and Jeff Wisoff, left the Shuttle's cabin at 12:48 UTC on 25 June.

Figure 5. Astronaut David Low, on the end of 'Endeavour's' robotic arm, approaches Eureca, stowed in the Shuttle's cargo bay, to help with the antenna boom latching

Figure 6. The Eureca Retrieval Mission Control Team at ESOC

Low attached himself at the top of the robotic arm, which was gently manoeuvred by Astronaut Nancy Sherlock to a position close to the first Eureca antenna. In the meantime, ESOC was uplinking the long sequence of telecommands that would re-activate the spacecraft subsystems to support the commanding of the antenna latches. All commands were successfully executed and a good telemetry link was established using minimum transmitter power on Eureca, so as not to endanger the astronaut operating in the vicinity of its transmitting antenna.

When the astronaut pushed the antenna into its fully retracted position, ESOC commanded the latches, confirming successful latching within a few seconds. The same procedure was executed successfully for the second antenna a few minutes later. However, some inconsistencies in the microswitch telemetry suggested a need for physical confirmation of successful latching by the EVA astronaut, who was moved back to the first antenna to verify that the boom could not be moved by tugging on it. This additional check meant that the Eureca-related EVA took a little more than the 60 min originally predicted.

The Carrier's deactivation followed very smoothly and at 16:30 UTC on 25 June Eureca was formally declared ready for return to Earth.

The next days of the Shuttle flight involved continuous temperature monitoring of Eureca via the Shuttle umbilical. Coordination between ESOC and NASA was mainly concerned with the attitude planning for the Shuttle operations, since the different attitudes had different effects on overall spacecraft temperatures and in particular on the very sensitive external hydrazine lines, which were also safety-critical items. Every attitude change was discussed and agreed between the two control centres, and a great deal of coordination was required each day to define the stable attitude for the crew's sleep period.

The first two landing attempts, on 29 and 30 June, were abandoned due to bad weather conditions at the primary landing sites.

Endeavour eventually touched down at Kennedy Space Center in Florida on 1 July at 12:53 UTC. Eureca had spent 11 months in orbit, circling the Earth more than 5000 times and successfully meeting all of its mission objectives, including demonstrating the feasibility of all of the deployment and retrieval operations involved and the robustness of the entire mission-control concept.

Eureca: The Flight Dynamics of the Retrieval

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In May 1993, the European Retrievable Carrier (Eureca) was lowered from a 490 to a 476 km orbit in preparation for its retrieval by the Space Shuttle on 24 June. This article reviews the flight-dynamics operations conducted by ESOC during the retrieval phase, including the manoeuvres that were performed by Eureca to reach the retrieval orbit, as well as the conditions and the philosophy that led to the final target trajectory.

Introduction

The European Retrievable Carrier (Eureca) was put into orbit by the Space Shuttle 'Atlantis' on 31 July 1992. Flight STS-46 lifted off from Cape Canaveral at 13:56:48 UTC following a smooth countdown. In orbit, Eureca was activated and removed from the cargo bay using the Orbiter's Remote Manipulator System (RMS). Whilst still attached to this robotic arm, Eureca's solar panels and its antennas were deployed (Fig. 1).

Release of Eureca from the arm took place during the 27th orbital revolution, on 2 August at 07:07 UTC and at an orbital altitude of about 426 km. Later the same day, the thruster engines of the spacecraft were activated for the first in a series of three burns which placed the Carrier in its operational orbit. The manoeuvre sequence was terminated on 7 August, with Eureca at its operational altitude of 502 km.

Eureca was retrieved from orbit eleven months later, at 13:54 UTC on 24 June 1993, by Space Shuttle 'Endeavour'. Designated as flight STS-57, the Orbiter performed a standard, ground-up rendezvous with Eureca, which had completed its own preparatory manoeuvring seven days before the Shuttle's launch. Prior to that, Eureca performed two orbit-correction manoeuvres on 20 and 24 May, followed by a small trim manoeuvre on 8 June, in order to reach and fine-tune the rendezvous orbit, which had to meet stringent constraints. Targetting of these manoeuvres and launch targetting of STS-57 was achieved by an integrated, iterative process between NASA and ESOC.

Under nominal conditions, Eureca could await the Orbiter 'passively' after reaching the rendezvous orbit. In the event of a significant Shuttle underspeed during ascent, Eureca would have to descend for rendezvous at a lower altitude. Under certain conditions, Eureca would even have had to perform a rapid emergency descent within four hours of the Shuttle's launch. This would have required a very time-critical and complex in-flight retargetting procedure, which had been prepared and intensively trained for with NASA.

The high-resolution, three-dimensional graphical representations that appear here* were prepared with the advanced tools of OAD's Orbit and Attitude Operations System, ORATOS (see accompanying panel). This system was used for the first time during the Eureca retrieval operations to generate a real-time, animated representation of the actual retrieval situation based on telemetry received from both Eureca and the Orbiter.

Preparing for rendezvous

Shortly after launch, in early August 1992, Eureca's thruster system was activated for a series of three burns, which placed the Carrier into its operational orbit at an altitude of 502 km. This altitude had been chosen such that it would decrease to the retrieval altitude of 476 km (257 nm) within the nominal mission duration of nine months due to the braking effect of air drag on the spacecraft. However, the air density at high altitudes depends strongly on the solar activity, which cannot be predicted precisely for periods of more than one month. Consequently, Eureca's end-of-mission orbital altitude turned out to be about 20 km higher than originally predicted.

* All graphics in this paper are based on the actual orbit and attitude data and on actual ephemerides during retrieval operations following Endeavour's launch on 21 June 1993, at 13:07:22 UTC. The only deviations from mathematically realistic geometries are the obvious exaggerations of the vehicle sizes in some graphics.

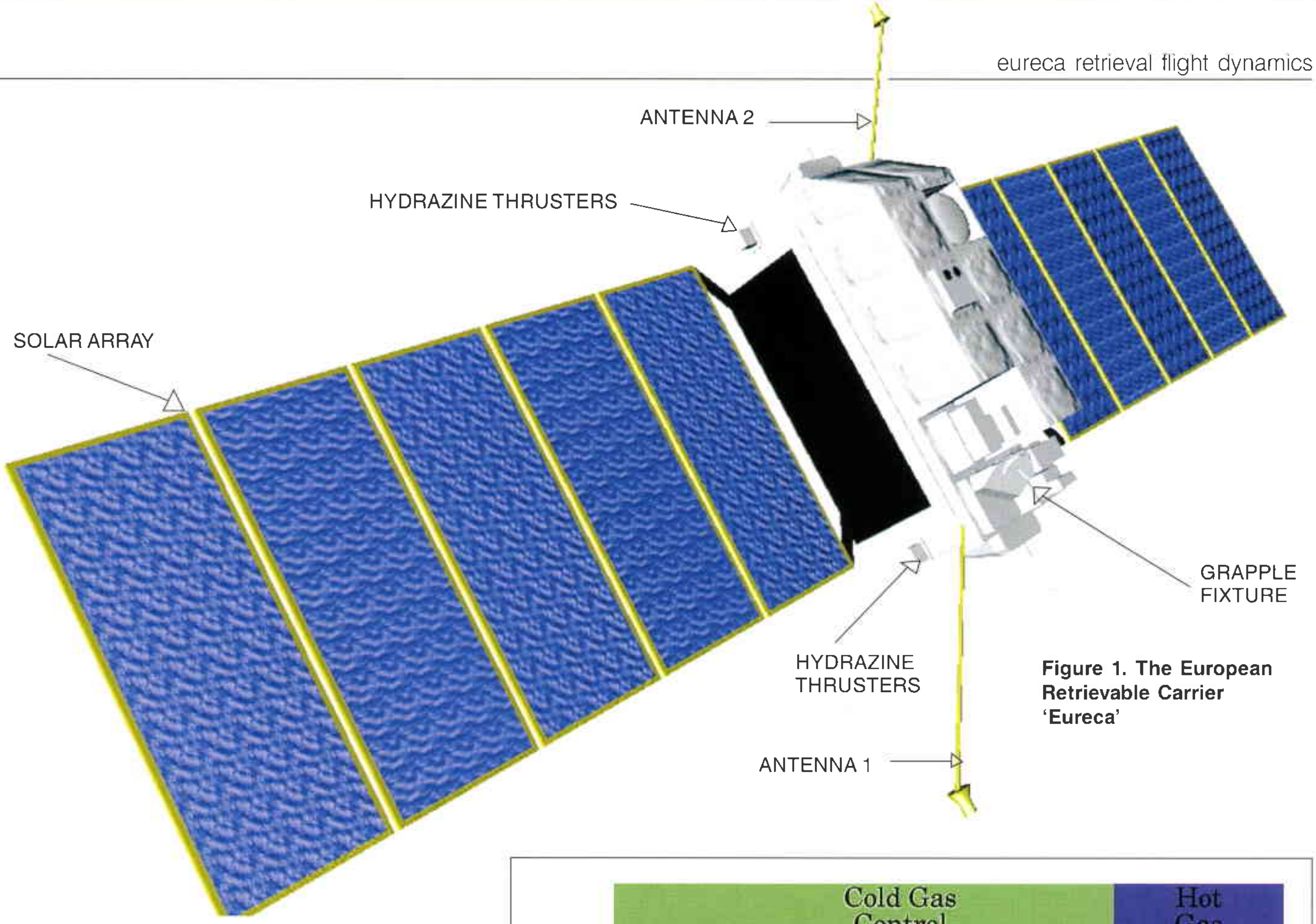


Figure 1. The European Retrievable Carrier 'Eureca'

The pre-retrieval adjustments of Eureca's orbit had more complex objectives, however, than just reducing the Carrier's altitude. The retrieval orbit was also required to be nearly circular and Eureca's orbital position relative to the Shuttle at retrieval launch (the so-called 'phase angle') had to be precisely controlled.

It is impossible to achieve an orbit that remains exactly circular at altitudes as low as the Eureca retrieval altitude. Deviations in the Earth's mass distribution from a perfect sphere cause the shape of such low orbits to oscillate with a period of about 33 days between near-circular and elliptic (Fig. 2). The maximum difference between apogee and perigee altitude in Eureca's case (Fig. 3) was 13 km. These periodic deviations grew much larger after 10 March 1993, after which Eureca's attitude was controlled with hot gas (using hydrazine as propellant) in order to conserve cold gas (nitrogen), which was used during the subsequent operational phase (Fig. 2).

Eureca's descent manoeuvre sequence into the retrieval orbit, which started on 20 May, had to compensate carefully for these effects, such that the periodic deviations in the orbit were within the Shuttle-prescribed limits.

A sequence of two burns was required to achieve the correct in-orbit position relative to the Shuttle. The first of these two burns

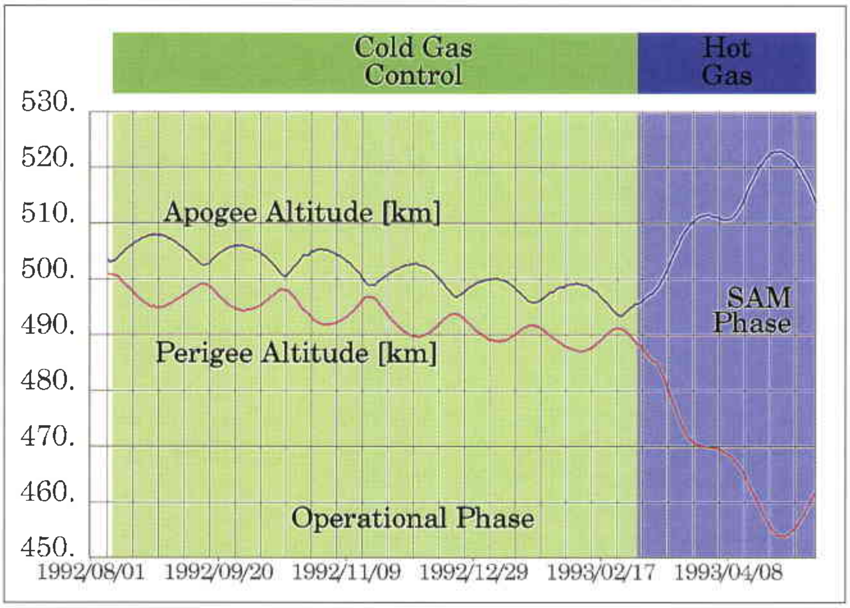


Figure 2. Orbital evolution during the operational phase

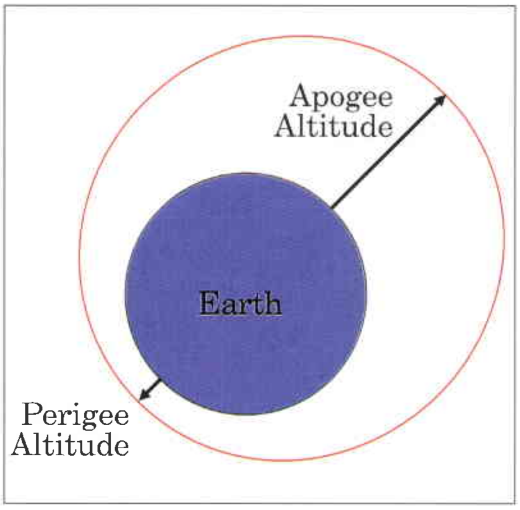


Figure 3. Apogee and perigee altitudes of an elliptical orbit

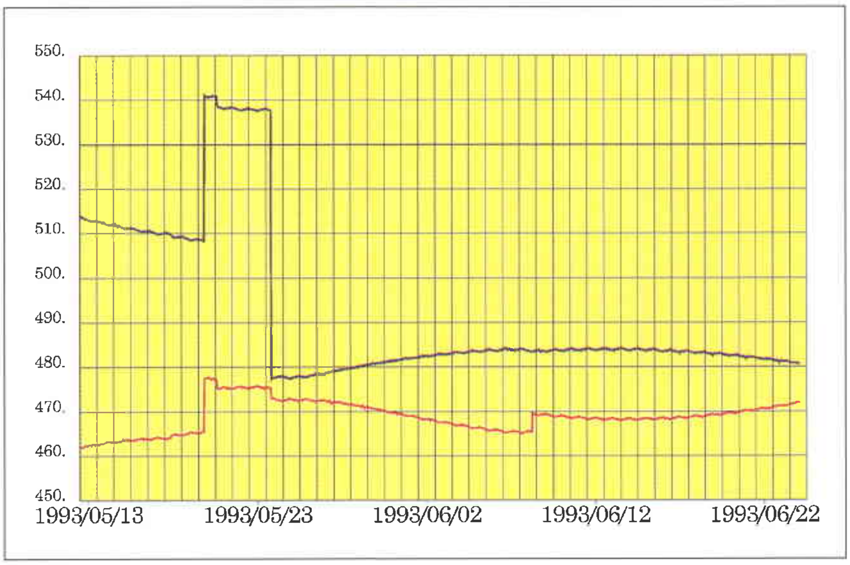


Figure 4. The descent to the retrieval orbit

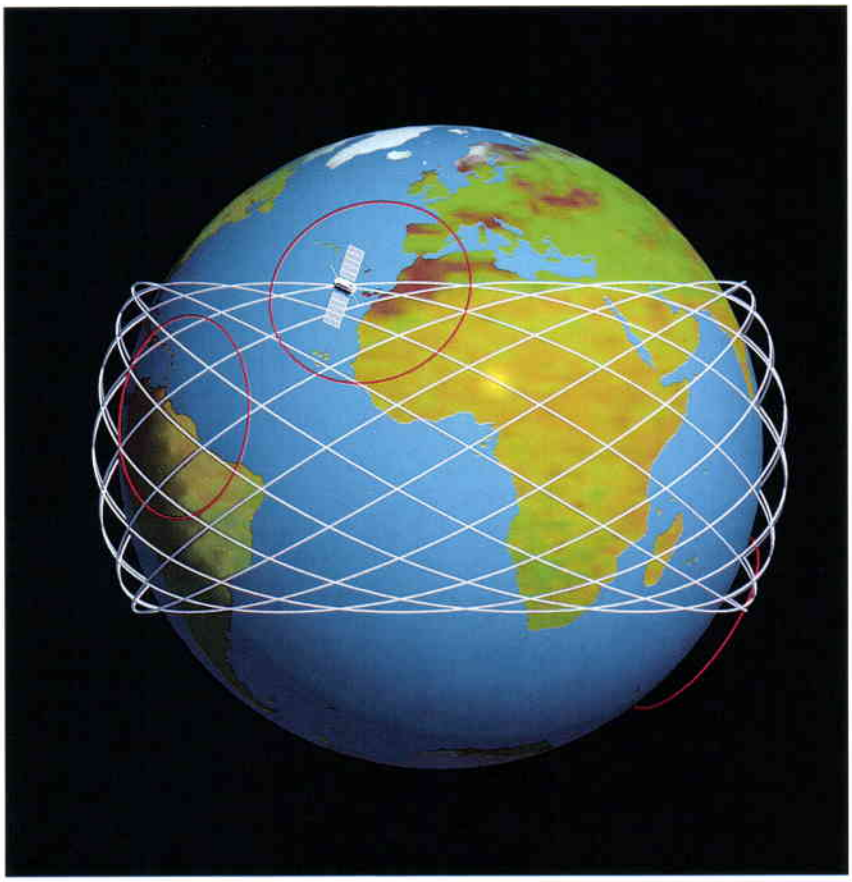


Figure 5. An Earth-fixed view of the Eureca phase-repeating orbit

actually increased the Carrier's orbital altitude (Fig. 4). After these manoeuvres, Eureca's attitude control was switched back to cold gas for minimising the orbit perturbations.

Waiting for rendezvous

By the time 'Endeavour' was launched from Kennedy Space Center, Eureca had completed its journey to the special retrieval orbit and was awaiting the Shuttle's approach.

The chosen retrieval altitude of 476 km was close to the maximum rendezvous altitude that the Shuttle can support. At this height, the influence of air-drag on Eureca was low and therefore its orbital altitude decayed only very slowly (less than 2 km per month). This meant that Eureca would remain safe even if the retrieval launch were significantly delayed, without any immediate need to perform an orbit-raising manoeuvre.

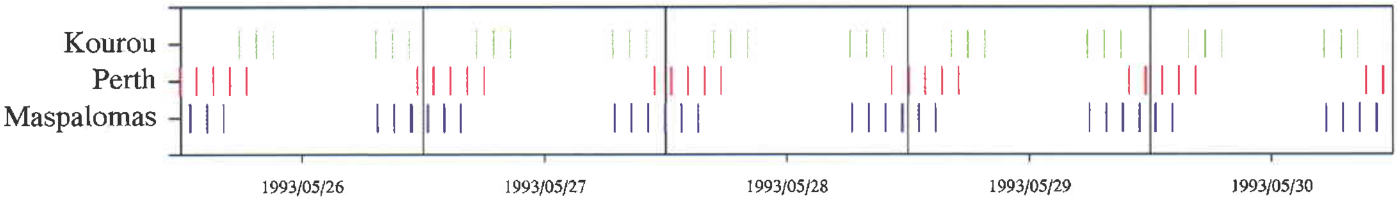
Additionally, the retrieval orbit's altitude was chosen such that Eureca's ground track repeated itself with a period of about 23.5 h. This special type of orbit, known as the 'Phase Repeating Orbit' (Fig. 5), eased the planning of the retrieval operations because largely identical launch and approach manoeuvre conditions for the Shuttle recur every 23.5 h. The contact periods of the ground stations at Kourou, Maspalomas and Perth with Eureca also exactly repeated with the same period (Fig. 6).

To achieve a phase-repeating orbit, a special match between orbital rate and precession rate of the orbital plane is required. Because Eureca's orbital plane precessed by 7° per day in the opposite direction to the Earth's rotation, it returned to the same position relative to the Earth's surface about once every 23.5 h. Within the same period, Eureca completed exactly 15 orbital revolutions.

Retrieval launch targetting

To rendezvous with Eureca, the Shuttle had to be injected into an orbital plane that was very close to the Carrier's, since it is impossible to change the Orbiter's plane significantly with the orbital manoeuvring system. Once in orbit, only 1° of plane change would cost as much fuel as raising

Figure 6. Station coverage for the phase-repeating orbit



the Shuttle's altitude by about 160 km, which is one third of the retrieval altitude.

In order to launch the Shuttle directly into Eureca's orbital plane, launch had to occur at the moment when the launch site passed beneath Eureca's orbit (Fig. 7). Since the Carrier's orbital plane was slowly precessing in inertial space in the opposite direction to the Earth's rotation (Fig. 8), this 'in-plane time' recurred approximately every 23.5 h.

Post launch, the Shuttle's orbital plane precessed slightly faster than Eureca's as long as the Shuttle was lower in altitude. To compensate for this, the Shuttle launch was not targetted exactly for the Carrier's orbital plane, but for a slightly offset 'phantom plane'.

Since it is practically impossible to achieve an 'instantaneous launch', the Shuttle uses a technique called yaw steering to achieve the correct 'phantom plane' following a launch during an extended period around the in-plane time. Yaw steering is out-of-plane thrusting performed by gimballing the Orbiter's main engines during the time between solid-rocket booster separation and main-engine cut-off. This technique allowed the launch window to be extended to a total of 72 min, opening 63 min prior to the in-plane time and closing 9 min after it.

Catching up with Eureca

In order to achieve rendezvous, not only must the orbital planes of both vehicles coincide, but also their altitudes. In addition, the phase angle between the vehicles (measured from the Shuttle's position projected onto the Eureca orbital plane to Eureca's position, as shown in Fig. 9) must be zero.

About 45 min after lift-off, at an altitude of about 467 km, the Orbiter activated its orbital manoeuvring system for an orbit-insertion manoeuvre, known as the 'OMS2 burn'. As the Shuttle launch took place near the beginning of the launch window, the phase angle at the OMS2 burn was 111.05° (it would increase to about 280° for a launch later in the window). Reduction of the phase angle to zero ('phasing') was accomplished via the faster orbital rate of the Shuttle in the lower orbit, allowing it to gradually catch up with Eureca (Fig. 10). The closing rate depends on the difference between the semi-major axes of the orbits of the vehicles.

The OMS2 burn, which determined the perigee altitude of the Shuttle (and thus the

Figure 7. Eureca's position at the opening of the Shuttle launch window on 21 June at 13:07 UTC

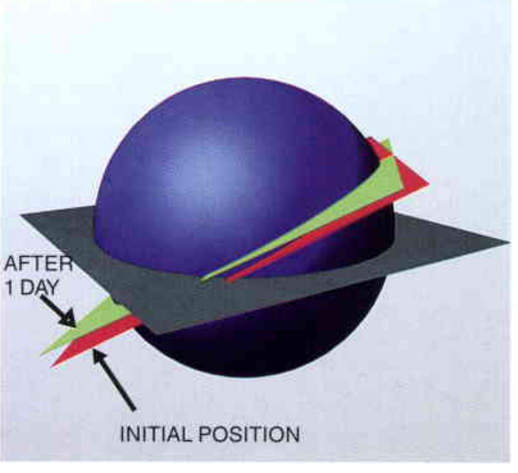


Figure 8. Precession of the orbital plane during one day

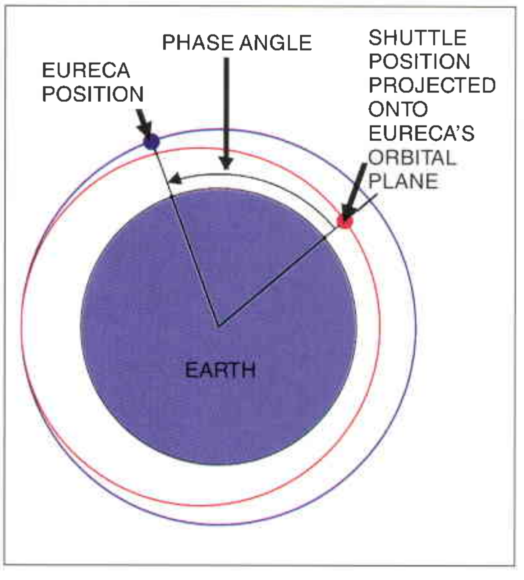


Figure 9. Phase-angle definition

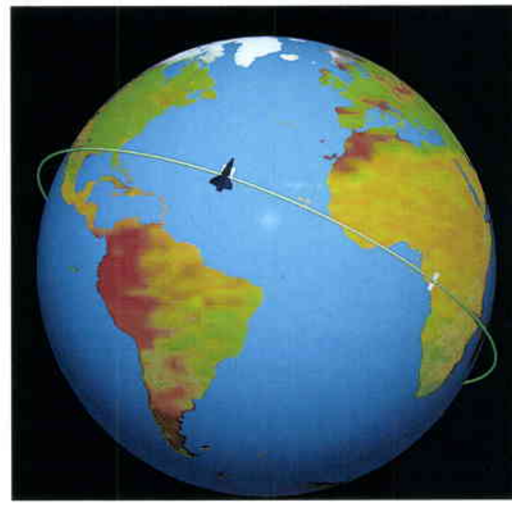


Figure 10. Orbital separation of Eureca and the Shuttle 03:14, 25:08 and 47:02 h after Shuttle lift-off, respectively

semi-major axis of the Shuttle's orbit), was targetted based on the amount of phasing required. The resulting Orbiter perigee altitude was 393 km; the phase angle initially decreased at a rate of 3.8° per Shuttle orbit.

Closing in on the target

The total amount of phasing that can be accomplished is determined by the closing rate and period of time allowed for phasing. This time period was fixed in that rendezvous was nominally scheduled to occur 3 days, 1 hour and 34 min after Shuttle lift-off.

During the phasing period, the Shuttle's perigee was gradually raised by a sequence of orbital manoeuvres which resulted in a gradual reduction in the closing rate with Eureca. Four manoeuvres (designated NC1 to NC4) were specifically designed for this purpose; NC1 occurred early in the mission, and the subsequent burns at the start of each crew working day.

Other manoeuvres that were required in support of a secondary payload, the Super Fluid On-Orbit Helium Transfer Experiment, were incorporated in the phasing plan in such a way that they too contributed to the gradual perigee raising. These manoeuvres are designated SH1 to SH3 in Figure 11.

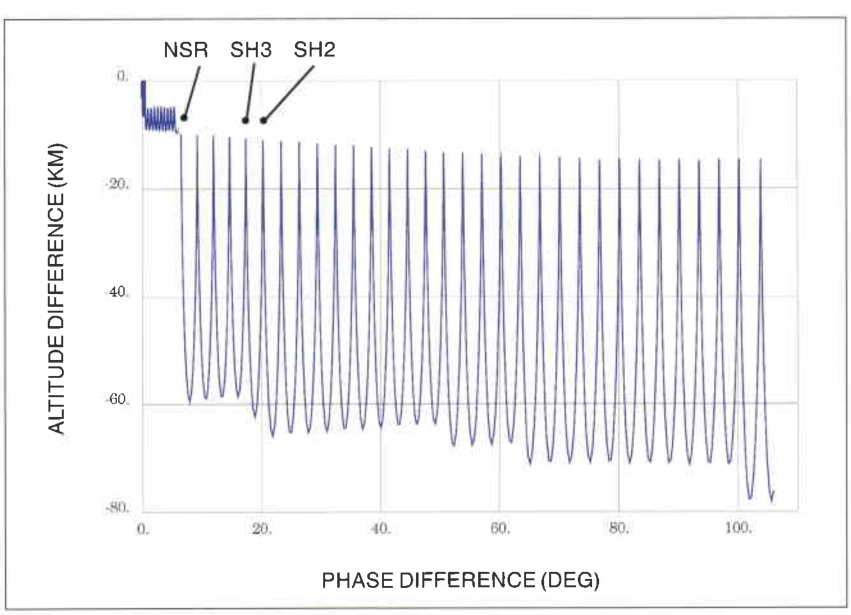


Figure 11. Shuttle motion relative to Eureca

The temporal evolution of the Orbiter's offset in phase and altitude illustrates the approach scenario (Fig. 11). As the Shuttle's orbit is elliptical, seen from Eureca it appears to perform an up-and-down motion during one orbit – an approach in 'leaps' (Fig. 12). It can be deduced from these figures that the Shuttle took more than forty orbital revolutions, each lasting about 90 min (and each corresponding to one of the 'leaps' in the relative-motion plot), before catching up with Eureca after three days of flight.

Detecting the target

The transition to proximity operations occurred early on the day of the rendezvous. Two days, 4 h and 48 min after launch, the Shuttle executed the first of two orbital-manoeuvre burns in order to synchronise the relative proximity motion with the orbital day/night cycle, to ensure good target visibility for the Shuttle's optical sensors and for the crew at the critical times for final navigation.

The first burn (indicated as NSR in Fig. 13) put the Shuttle into an orbit with almost the same shape as Eureca's, and aligned with it ('co-elliptic orbit', shown in Fig. 14). The Orbiter travelled below and behind Eureca until the NH burn. The latter, which took place at orbital midnight, raised the Shuttle's apogee by about 400 m above Eureca's orbit. Thereafter, Orbiter perigee always occurred at orbital midnight and Orbiter apogee (and thus the remaining phasing manoeuvres) always at orbital noon.

The NC4 burn was in fact performed at the orbital noon directly after the NH burn at a distance of 82.5 km behind Eureca. The TI ('Terminal-phase Initiation') burn occurred at orbital noon two orbits later. It enabled the Shuttle to intercept Eureca in slightly less than one orbit. Preceding the TI burn by 1 h is a 'corrective combination' burn (labelled NCC), which fine-tuned the position of the TI burn. Both of these burns were targetted onboard the Orbiter by using star-tracker measurements of the direction from the Orbiter to Eureca. This direction could be measured optimally during the 'orbital evenings' of the two orbits prior to the TI burn, when Eureca was brightly illuminated by the Sun from behind the Shuttle.

The final approach

Following the TI burn, on the final drift arc to the target, four targetted 'mid-course correction manoeuvres' (designated MC1–MC4) were performed. Two minutes after MC4, which occurred 1 h 13 min after the TI burn and slightly more than 1 h prior to the 'grapple', the crew acquired visual contact with Eureca and began to pilot the Orbiter manually towards its target. At this time, the Orbiter was passing below Eureca ('R-bar crossing'), at a distance of about 600 m.

After assuming manual control, the pilot performed three major discrete braking manoeuvres at relative distances of about 600, 450 and 300 m, respectively. Many more smaller braking manoeuvres were performed during the final 300 m of approach. Figure 16 shows the actual approach trajectory flown by STS-57 as monitored in real-time at ESOC from Shuttle telemetry.

Some 25 min after assuming manual control, the Orbiter crossed Eureca's path from below, about 120 m ahead of the

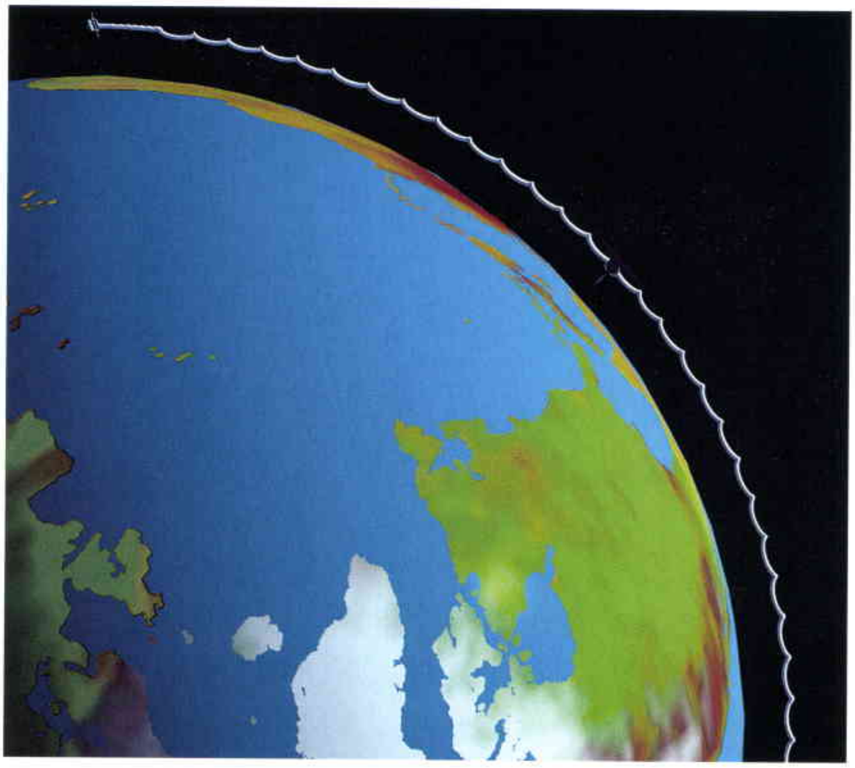


Figure 12. Shuttle's approach to Eureca as seen from above the orbital plane

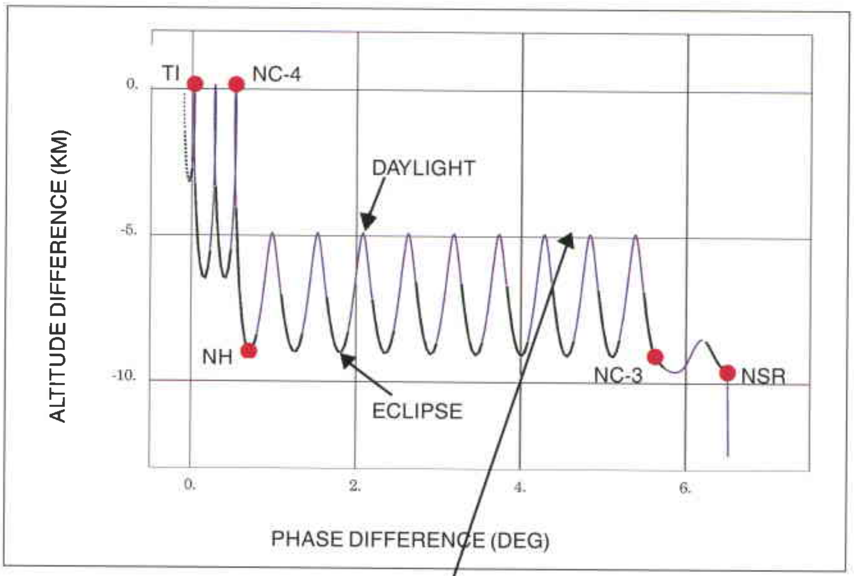


Figure 13. Relative motion during the proximity phase

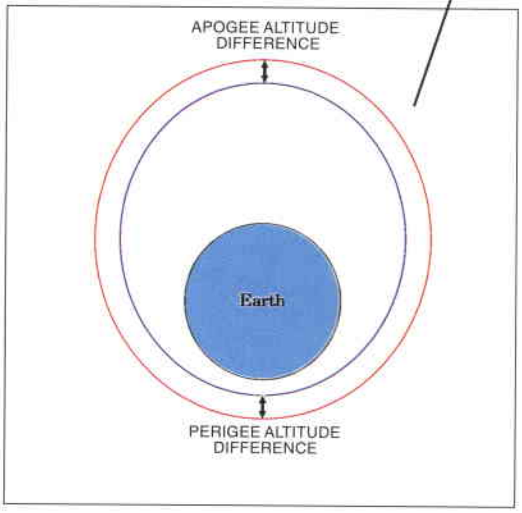


Figure 14. Nearly co-elliptic orbits

Figure 15. Positions and attitudes of Eureca and the Shuttle at R-bar crossing, V-bar crossing and shortly before grapple

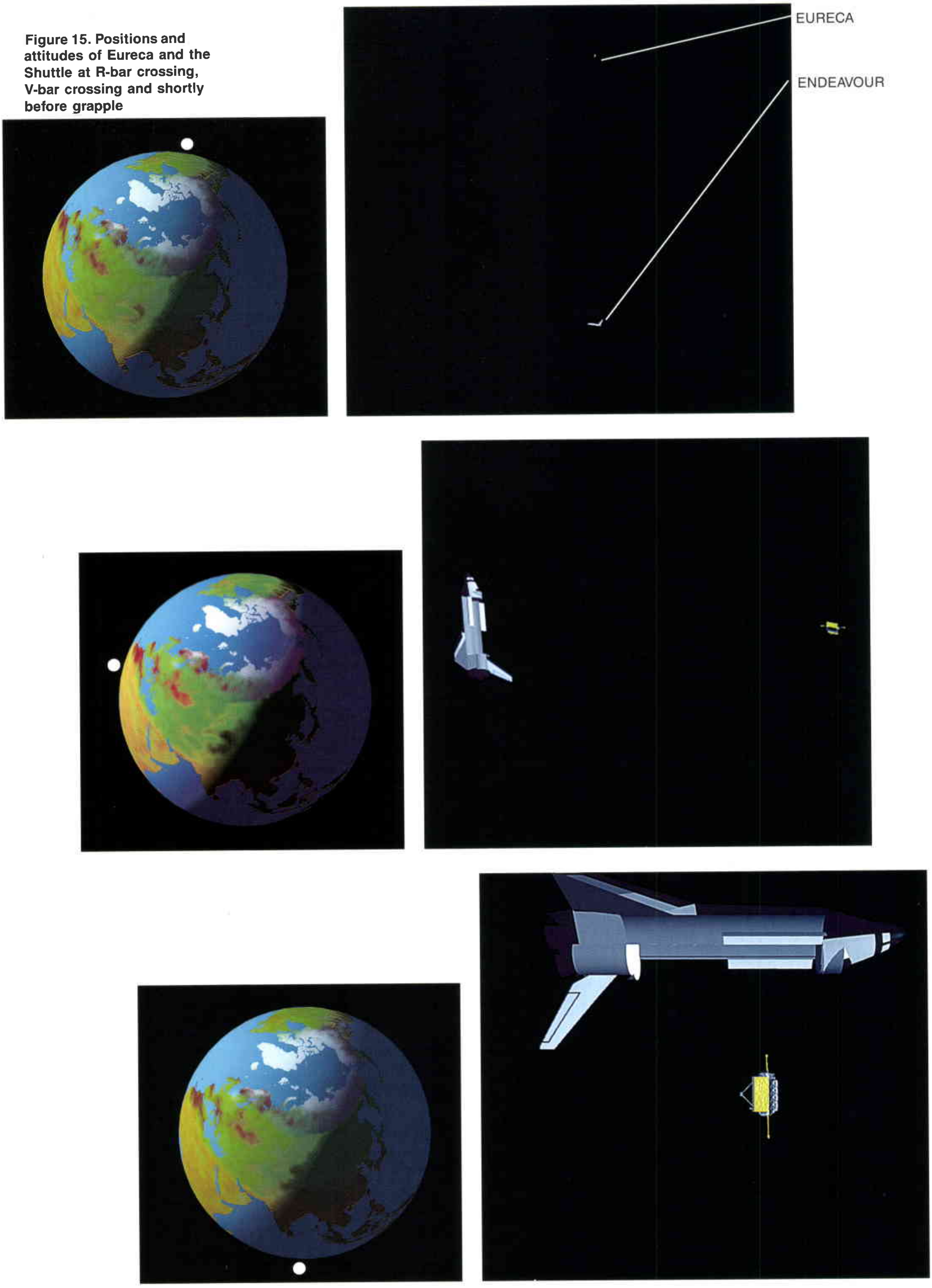
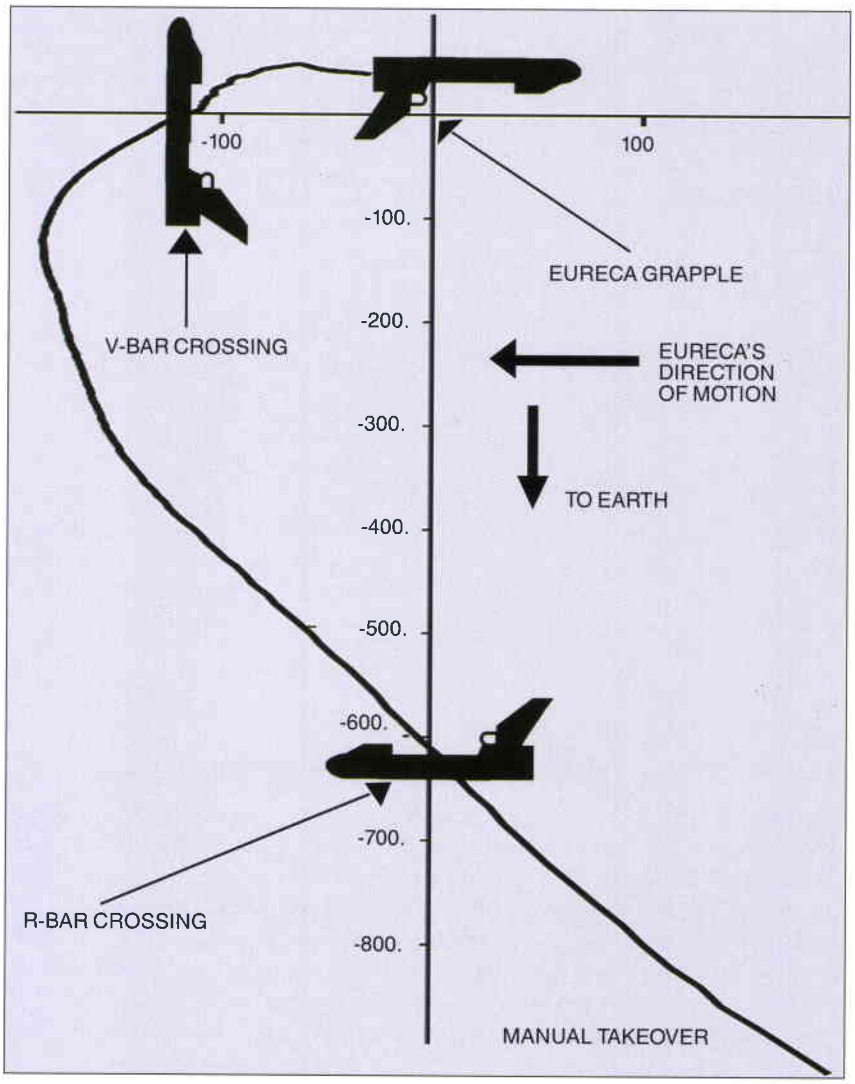


Figure 16. The final approach trajectory flown by the Shuttle, as monitored in real-time at ESOC from Shuttle telemetry



Carrier ('V-bar crossing'). The Orbiter then continued its approach until Eureca appeared in the field of view of a camera attached to the end of the Shuttle's Remote Manipulator System (RMS). At this point, with Eureca within reach, rates were nulled and the approach sequence was terminated.

Making physical contact: the 'grapple'
During the proximity phase, the attitudes of both Eureca and the Orbiter were inertially fixed. Examples of the real-time graphical representations of the positions and altitudes of both spacecraft are shown in Figure 15. The Orbiter flew with its wings perpendicular to the orbital plane. During orbital day, the Sun always illuminated the Orbiter from the front, appearing about 10° to the left of the Shuttle's nose, with the solar elevation ranging from 8° below to 32° above the Orbiter. This ensured good viewing conditions (no Sun blinding) for the crew, who were able to observe Eureca through the upper and rear windows during final approach and whilst the RMS was being operated.

Eureca's solar panels were perpendicular to the orbital plane, facing in the same direction as the Orbiter's nose. This attitude remained unchanged when the panels were retracted about 1 h 40 min prior to the grapple.

In addition to the attitudes of the two vehicles, the Orbiter's line of approach to Eureca was also inertially fixed. Eureca was therefore visible during orbital day with the same lighting conditions at a continuously decreasing distance directly above the Orbiter's cargo bay. The Orbiter's arm was 'poised for capture', i.e. fixed in a special position ready to grapple Eureca.

When the approach was completed, the hand of the arm ('end effector' of the RMS) needed to be aligned with a special handle on Eureca ('grapple fixture') to which it had to attach. Rather than move the arm, this was achieved by rotating the entire Shuttle about the line of approach.

The grapple marked the successful conclusion of the Orbiter's three-day journey to its orbital rendezvous with Eureca.

The Orbit and Attitude Operations System (ORATOS)

'ORATOS', ESA's future Orbit and Attitude Operations System, will be in use from the mid-nineties until well beyond the year 2000. Behind its design lies the experience gained in providing flight-dynamics support to all of ESA's earlier missions.

The ORATOS software runs on powerful UNIX work stations, with file servers for the mass-storage of shared data. A local area network provides interconnectivity.

The software itself is structured into three layers. The *applications layer* contains the flight-dynamics discipline-specific software. The *operating systems layer* contains the UNIX operating system and associated tools for graphical user interfaces and communications. The *support layer*, which decouples the applications from the lower-level system tools contains facilities for systems management, communications and data dissemination and man/machine interfaces.

The high-resolution, three-dimensional graphical representations in this article have been generated using the prototype man/machine interface facilities of ORATOS. A prototype of ORATOS's three-dimensional animation system was used for the first time operationally during Eureca's retrieval to generate a realistic, animated representation of the retrieval situation in real time, based on telemetry received from both Eureca and the Orbiter.

The ESA Microgravity Database

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Introduction

The first European microgravity experiments were carried out on a Texus sounding rocket more than a decade ago. Since then, space flights dedicated to microgravity research, either organised in Europe or with European participation, have been successfully performed in ever-increasing numbers. Several hundred experiments in various fields of research have yielded an impressive collection of scientific results.

To facilitate and optimise access to the results of previous microgravity experiments, ESA is establishing a Microgravity Database (MGDB). The database will give scientists access to descriptions of all experiments related to microgravity research carried out on ESA and NASA missions since the 1960s. MGDB incorporates both a local database available for PCs and Apple Macintoshes, and a remote database which can be accessed via the ESRIN Data Dissemination Network (DDN) and public X.25 networks.

However, microgravity is a research tool rather than a self-standing scientific discipline. This can make it difficult to trace experiment results in the literature and scientific databases.

Also, because flight opportunities for microgravity experiments are rare, it is extremely important to be able to access the results of previous experiments. Those results might not be conclusive but, with the conclusions of other investigators, a scientific problem can be better understood, thus enabling the definition of further, meaningful experiments. Moreover, the availability of information on all experiments performed as well as on planned ones prevents the wasting of valuable resources.

The MGDB system

In order to provide this information, ESA's Microgravity and Columbus Utilisation Department initiated the Microgravity Database (MGDB) project in June 1991. Potential users in ESA's head office and participants in the 1991 Columbus Symposium were interviewed, and the user requirements were identified. The functionality of related, existing systems was also analysed. The implementation phase then began in February 1992. The first version of MGDB, the PC/Windows version, is planned to be ready for distribution in autumn 1993.

Some characteristics of the system are:

— Scientists are able to identify within a short time all those microgravity experiments related to a scientific topic.
— The database provides preliminary information on the experiments in the form of an abstract.
— An exhaustive list of bibliographical references for each experiment is supplied.
— All experiments performed, for example, on one mission or by one investigator, can be displayed.

With this system, queries about the microgravity experiments are performed using intuitive visual objects like menus, forms and dialogues, thus eliminating the need to learn a specific query language such as SQL, or the internal structure of the database. In addition, the system allows users to navigate through the database by means of hyperlink techniques, simply by pinpointing existing correlations between the various elements. Once a specific experiment has been retrieved and displayed, the user can receive and immediately browse through all the information related to it, including displaying an image illustrating the experiment set-up, or branching to related experiments.

The MGDB data

MGDB gives scientists access to documentation on all microgravity-related experiments performed during ESA and NASA space missions since the 1960s and some Japanese missions (Table 1). Currently, 997 European, American and Japanese microgravity experiments are included in MGDB.

The information has been obtained from two sources:

— The ESA Catalogue of Microgravity Experiments, which is currently compiled by the European Microgravity User Support and Operation Centres
— The Fluids and Materials Processing Experiments Database (FAME), compiled by C. Winter (NASA Marshall Space Flight Center).

Structure of the information
The information in MGDB has been structured in such a way as to allow the quick and efficient retrieval of the requested information. MGDB has a hierarchical structure, with three levels (Fig. 1):

— the database
— the disciplines
— the research areas.

Table 1. Missions included in MGDB

European Missions	
1970 – 1980:	Texus 1; Texus 2; Texus 3; Texus 3A; SPAS-1
1981:	Texus 3B; Texus 4
1982:	Texus 5; Texus 6
1983:	Texus 7; Texus 8; Spacelab 1
1984:	Texus 9; Texus 10; STS-9 (SL1)
1985:	Texus 11; Texus 12; Spacelab D1
1986:	Texus 13; Texus 14A
1987:	Texus 14B; Texus 15; Texus 16; Maser 1
1988:	Texus 17; Texus 18; Texus 19; Texus 20; Aragatz; Maser 2
1989:	Texus 17 (C.010); Texus 21; Maser 3
1992:	Eureca 1; Texus 23; Texus 24
1993:	Spacelab D2
U.S. Missions	
1960 – 1970:	MA-7; WASP-1; Mercury-Aurora 7 (MA-7)
1970 – 1975:	Apollo 14; Apollo 16; Apollo 17; Skylab, Sl-2; Skylab, SL-3; Skylab SL-3S; Skylab SL-4; Spar 1
1975 – 1980:	Spar 2; Spar 3; Spar 4; Spar 5; Spar 6; Spar 7; Spar 8; ASTP
1981:	Spar 9
1982:	STS-003 (OFT-3 Columbia); STS-004 (OFT-4 Columbia); STS-005 (31-A Columbia)
1983:	Spar 10; STS-006 (31-B Challenger); STS-007 (31-C Challenger); STS-007 (31-C Challenger); STS-008 (31-D Challenger)
1984:	STS-011 (41-B Challenger); STS-13; STS-014 (41-D Discovery); STS-017 (41-G Challenger); STS-019 (51-A Discovery)
1985:	Spacelab 2; Spacelab 3; STS-020 (51-C Discovery); STS-023 (51-D Discovery); STS-025 (51-G Discovery); STS-027 (51-I Discovery); STS-031 (61-B Atlantis)
1986:	STS-032 (61-C Columbia)
1988:	STS-26 (Discovery)
1989:	Consort 1; Consort 2; STS-29 (Discovery); STS-32 (Columbia)
1990:	Consort 3
1991:	Consort 4; STS-40
1992:	STS-42 (IML-1 laboratory)
1993:	STS-47; STS-50; STS-52
Japanese Missions	
1980:	TT-500A8; TT-500A8
1981:	TT-500A 10
1982:	TT-500A 11
1983:	TT-500A 12; TT-500A 13

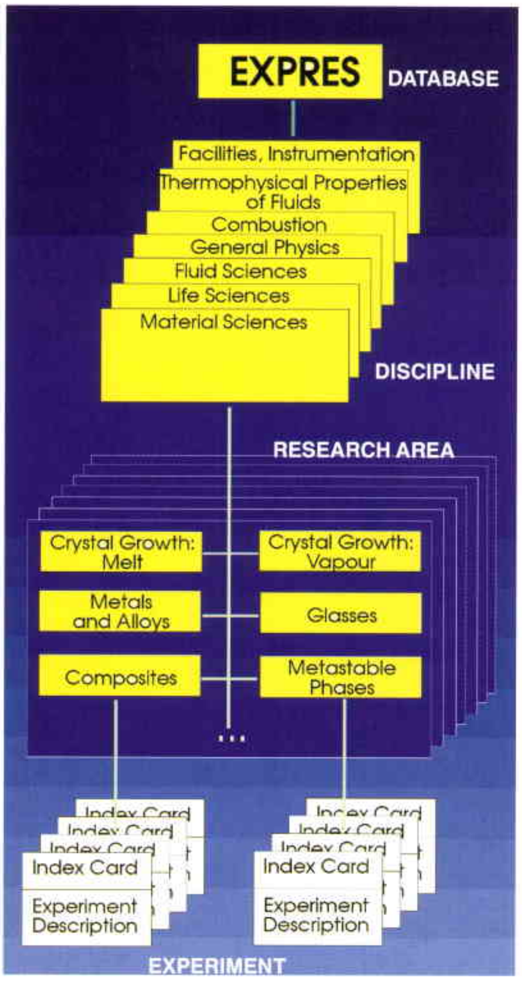

Figure 1. Structure of the MGDB information

The database, called ExpRes (from EXPeriment RESults), is divided into disciplines, such as material sciences or life sciences, each covering a range of specific areas.

Each discipline is subdivided into research areas, for example, the material sciences discipline contains areas covering studies on crystal growth, metals and alloys, glasses, composites and metastable phases. Each experiment is assigned to one or more research areas.

It is possible to search the entire database or to restrict a query to one or more specific disciplines or research areas.

Table 2. The information on one experiment, as it is stored in MGDB

Experiment Title	Freezing of a long liquid column
Flight/Mission	TEXUS 18
Launch Date	88/05/06
Discipline	Life Sciences
Research Area	Fluid Statics and Capillarity
Investigator(s)	MARTINEZ, I.; SANZ, A.
Investigator Affiliation	Escuela Tecnica Superior de Ingenieros Aeronauticos, Madrid (Spain).
Facility	Texus Experimental Module (TEM) 06-9
References	MARTINEZ, I. Liquid bridge analysis of silicon crystal growth experiments under microgravity. J. Cryst. Growth, 75, 1986 : 534-544 MARTINEZ, I. Stability of long liquid columns in Spacelab D-1. In : 6th Eur. Symp. Mat. Sc. under Microgravity Conditions (Bordeaux, 1986) ESA-SP-256, 235-240 SANZ, A. The crystallization of a molten sphere. J. Cryst. Growth, 74, 1986: 642-655 MARTINEZ, I., et al. Freezing of a long liquid column on the TEXUS 18 sounding rocket flight. ESA Journal, 12, 1988: 483-489
Major Keywords	COLUMNS (SUPPORTS); FREEZING; LIQUIDS; SOLIDIFICATION
Minor Keywords	COOLING; HEAT MEASUREMENT; INTERFACIAL TENSION; LIQUID-SOLID INTERFACES; TEMPERATURE WATER
Source	ESA-SP-1132
Date of Last Update	1991/02/01
Validation Note	Minster, O. (ESA)
Experiment Objectives	Measurement of the contact angle between the free liquid surface and the solid/liquid interface during the longitudinal solidification of a liquid column.
Experiment Procedure	The module developed for the previous experiment was reused after upgrading. A column of water of 30 mm in diameter and 86 mm in length was formed under microgravity conditions (at 2 mm/s over 80 mm and with a smooth deceleration over the last 6 mm). One support was then cooled down in order to achieve a directional solidification of the column. The experiment was recorded with a CCD camera and tracer particles were used to visualize the motions in the liquid induced by surface tension gradients and volume changes on solidification. The slenderness of the column was chosen close to the critical one: L/D = 0.91(L/D)cr, in order to enhance its sensitivity to small forces. Three thermocouples were located in the cooling support, for temperature and heat flux measurements. Five others in an array were inserted radially into the column to measure the temperature field in the liquid.
Experiment Result	Comparison of its perfectly cylindrical shape with shapes recorded during previous experiments indicates that the residual accelerations of the rocket were much less than 0.00007 g. The good resolution of the TV-pictures during ground tests could not be reproduced during flight and a precise measurement of the receding angle could not be achieved. The solidification front seemed to remain plane. Although the thermal gradient measured in the liquid was of the order of 10°C/mm (Fig. 2) and the thermal coefficient of the surface tension of water is high, no convection occured (the tracers stayed nearly at rest). This is interpreted as the effect of impurities which strongly reduced the surface tension of water. A temporary opacity of the liquid was observed close to the cooling support just before the appearance of the first ice crystal. A peak in the temperature recordings of the cool support seems to indicate the occurence of undercooling and subsequent release of solidification enthalpy. The re-entry of the rocket caused the breakage of the remaining liquid part of the column. The ice crystal obtained, which stayed on the cooling support (Fig. 3), was 13 mm long, as anticipated. During future microgravity experiments, the growth of a single crystal should be triggered in order to assess the influence of the crystallographic orientation on the receding angle.

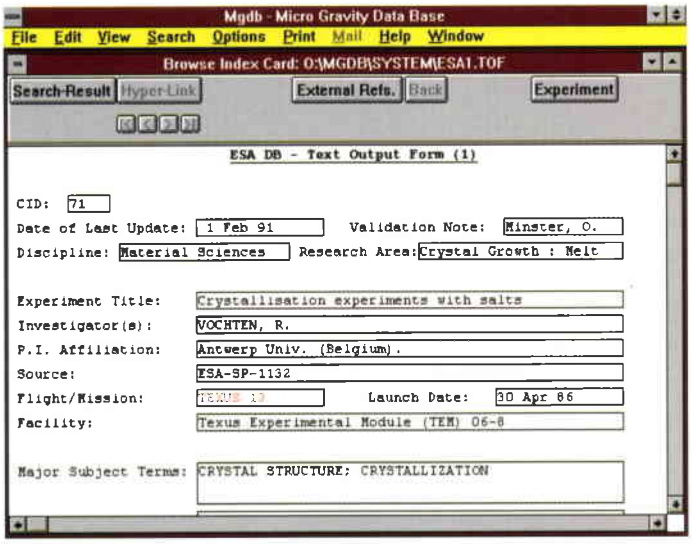

Figure 2. An index card, displayed after searching for 'Texus missions' (the search term is highlighted)

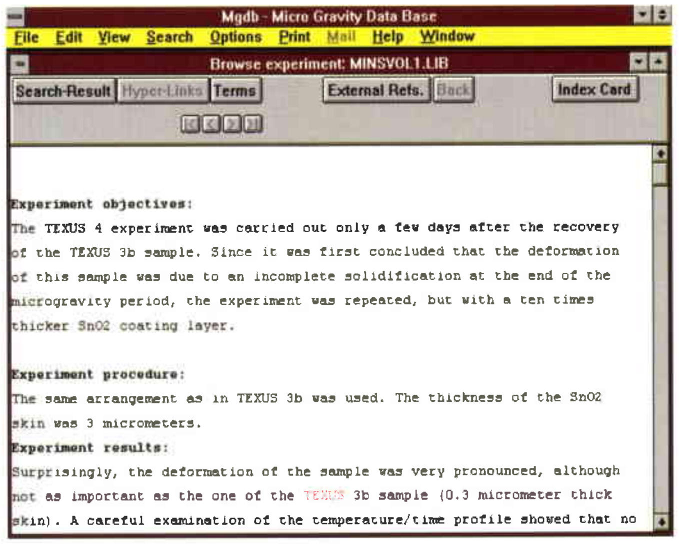

Figure 3. An experiment description, displayed after searching for experiments with 'Texus' in the Experiment Results field (the search term is highlighted)

An example of the information about an experiment, as it is stored in MGDB, is given in Table 2. For each experiment, the documentation consists of an 'index card' and a description of the experiment which can include images:

— The index card (Fig. 2) gives an outline of the experiment, for example its title, when and on which mission it was conducted, the principal investigators, a list of keywords, validation notes, the experiment facility and payload description, evidence on related experiments as well as bibliographic references.
— The experiment description (Fig. 3) summarises the objectives, procedures, and results of the experiment on one to two pages of text.

MGDB provides hyperlinks within the information (Fig. 4). They allow the user to move quickly and easily within the database. While browsing through an index card or an experiment description, the user can:

— branch to a related experiment
— view an image that is linked to the experiment, such as a drawing of the experiment set-up or a diagram illustrating the results (Fig. 5)
— display other related objects such as a video sequence.

The hyperlinks are only available where they are appropriate. Those available are indicated on the index card or the experiment description either by mouse-sensitive push-button icons or underlined text.

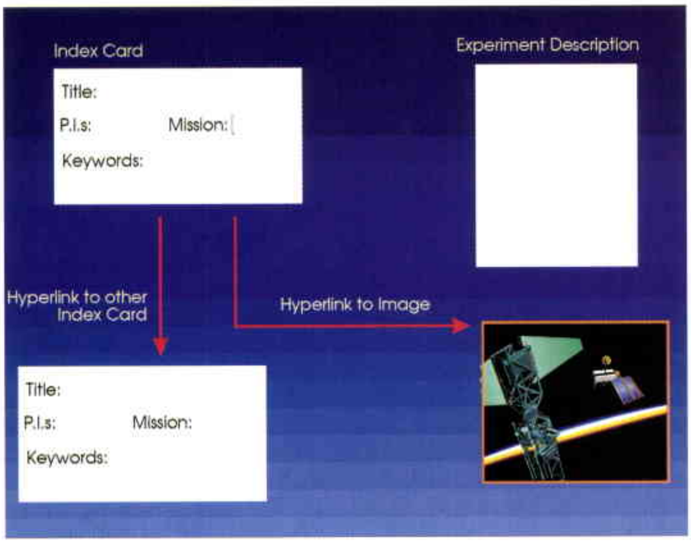

Figure 4. Hyperlinks allow the user to move quickly and easily to related information, such as to another index card or to an associated image

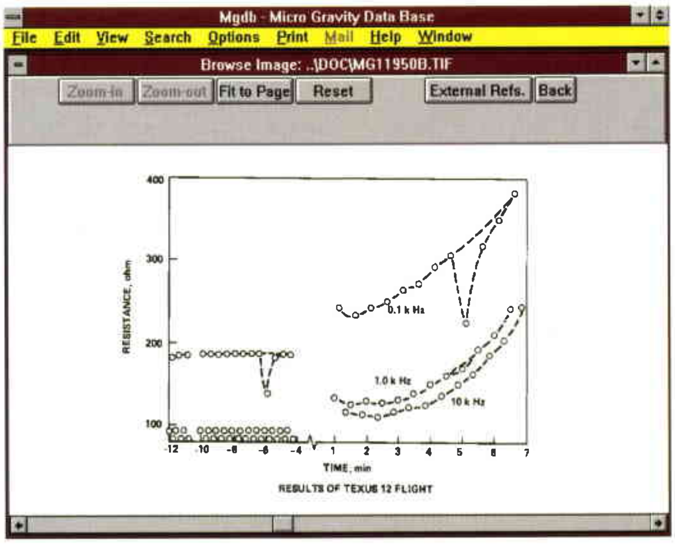

Figure 5. An image hyperlinked to an experiment description, in this case showing the results of the experiment

Using MGDB

Figure 6 shows the steps a user takes to retrieve information during a typical search session. At each step, the user can print the retrieved information, or save it in a file.

Making a query

The basic tool for defining the search criteria for a query is the 'query form' screen. Like the index card, it provides a structured set of fields in which the user enters the criteria for the query to be performed. Each field on the form causes the system to search a specific part of the database. For example, to search for experiments conducted during a specific mission, the user enters the mission name in the 'Flight/Mission' field.

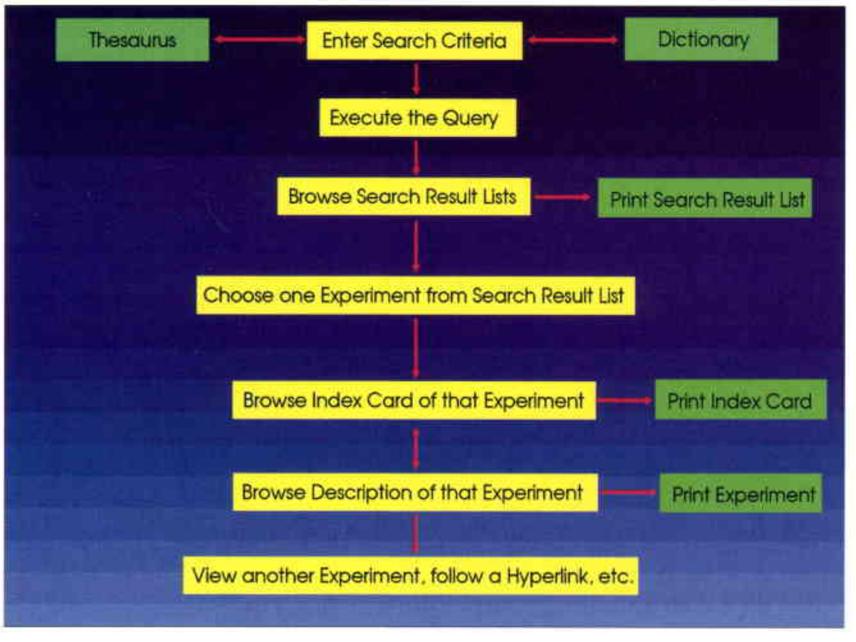

Figure 6. How to retrieve information

Complex queries

More complex queries can also be performed. The retrieval system supports most kinds of Boolean and numeric search operators:

— AND. Retrieve those experiments that dealt with both 'Marangoni convection' and 'crystallisation'.
— OR. Retrieve all experiments that were flown on Spacelab-1 or D1.
— NOT. List all microgravity experiments on D1 that did not deal with Marangoni convection.
— Date Operators. List those experiments that were conducted before, after, or within a certain timeframe. The system also allows Boolean operations to be applied to numeric values.
— Truncation. When the query 'bio*' is entered in the 'Keywords' field, retrieve all those experiments dealing with bioceramics, biology, biomaterials, biomedicin, biotechnology, etc.
— Masking. Use single character wildcards, such as 'Texus 14?', to specify Texus 14A and Texus 14B.
— Proximity. Search for terms that appear within a certain range of each other; for instance, retrieve those experiment descriptions that contain the terms 'sulphur' and 'liquid cast iron' in the same paragraph.
— Search for groups of words, for example, 'electrostatic positioning system' in the experiment description.

Query expressions within a field can be rather complex, and incorporate several levels of parentheses. It is also possible to query using more than one field of the index card or the experiment description simultaneously.

Facilitating query formulation

To simplify using the query interface, the system can display the list of words and phrases that can be used in a specified field of the index card. This dictionary also shows how often and in how many different experiments a particular word or phrase has been used. The dictionary can show all those terms 'alphabetically close' to the one entered by the user. In this way, data entry errors in the query can be easily detected.

Figure 7 shows another tool that is provided with the system: a microgravity thesaurus which contains approximately 8000 terms in several forms such as synonyms, related terms, and scope notes on terms. Terms from both the thesaurus and the dictionary can be copied into the query form simply by clicking on them with the mouse.

Search results

When a search has been executed, the system displays a 'search result list' which shows the experiments that match the search criteria (Fig. 8).

A double click with the mouse on one of the experiments in the search result list brings up its index card, which gives outline information on the experiment. There, the search terms entered in the query form are highlighted.

The additional information for each experiment (description, hyperlinked text, images) can be accessed at this point with a simple click of the mouse.

Additional functions

The system provides means to combine the results of several queries, i.e. it is possible to base a new query on the result of a previous

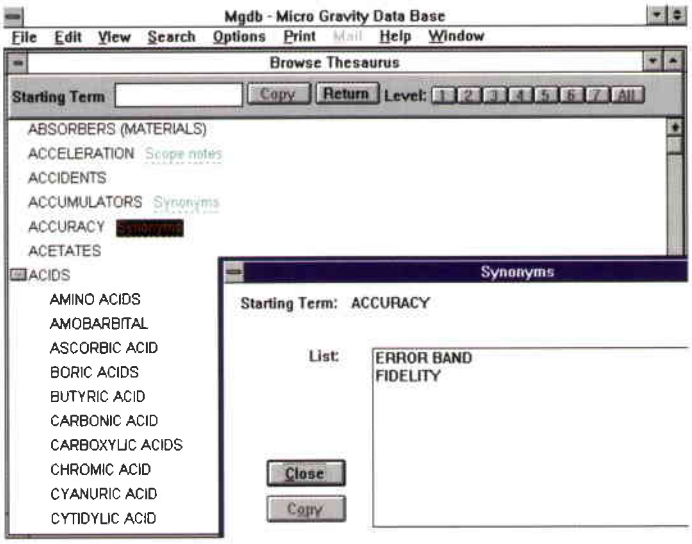

Figure 7. The microgravity thesaurus, offering synonyms for the term 'accuracy'

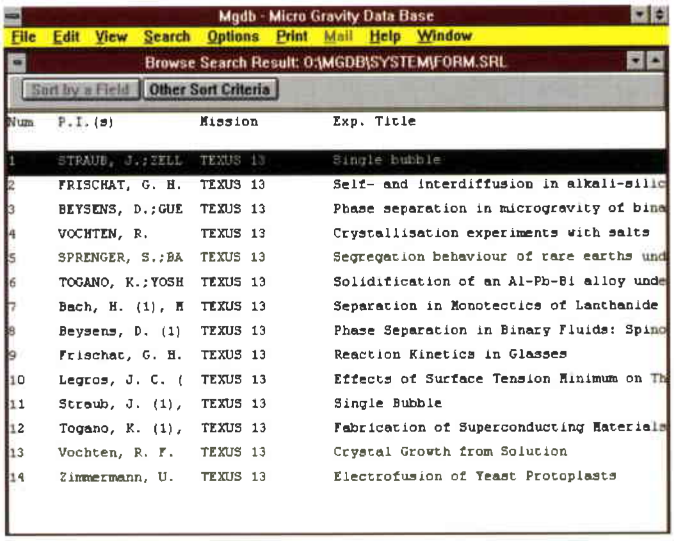

Figure 8. A search result list, displayed after searching for microgravity experiments on Texus 13

one. In this way, a search result can be refined, i.e. the next query will only search from among the results of the previous one. It is also possible to add one search result list to another one, or to exclude a search result set from the next query.

Furthermore, the system maintains a list of all queries that have been performed during a session, together with the results obtained.

Accessing MGDB

The data is available both locally on a PC and remotely on a host computer located at ESRIN in Frascati, Italy:

— Local access
  In this case, the database and the software required to access MGDB are installed on the user's PC. Updates are provided on diskettes or on CD-ROM.

  The data delivered on diskettes does not include images due to storage space constraints. The database delivered on CD-ROM includes approximately 500 images. In a later version, video sequences may be made available.

— Remote access
  The latest version of the ExpRes database is maintained on a host computer at ESRIN. Users connect to the host via the ESA Data Dissemination Network (DDN) and X.25 PSPDN, using communications software included in the system.

The user interface is identical for both the local and the remote system (Fig. 9).

Hardware and software requirements

MGDB uses Fulcrum's Ful/Text software for its information retrieval. This is delivered to the user with the system.

On the PC, the following basic configuration is required:

— Microsoft Windows version 3.0 or later
— 10 MB of free hard-disk space (mostly for data) or a CD-ROM reader.

MGDB for Macintosh computers will be ready for distribution in early 1994. The requirements will be:

— 4 MB of RAM
— System 7 or a later version
— 10 MB of hard-disk space (mostly for data) or a CD-ROM reader.

Figure 9. The client-server architecture

Project Status

Data collection

The experiment descriptions have been collected from two sources:

1. The European User Support and Operation Centres (USOC) — CADMOS in France, MUSC in Germany, DUC in the Netherlands and MARS in Italy — compiled information on European missions, under a contract with ESA. Leading ESA microgravity scientists monitored the quality of the work. The experiment collection is presently being enlarged.

2. The Fluids and Materials Processing Experiments (FAME) database, compiled by C. Winter and J. Jones (NASA Marshall Space Flight Center, Huntsville, Alabama) and sponsored by NASA Headquarters' Microgravity Science and Applications Division. ESA and NASA have signed an agreement concerning the exchange of data between the two organisations.

In the future, it is planned that NASA will compile experiment descriptions from U.S. missions, while the USOCs will focus on European missions. The data will be exchanged and made available to the user community at regular intervals.

Moreover, 15 000 microgravity-related bibliographical references to published and unpublished ('grey') literature have been collected from databases hosted by ESA-IRS at ESRIN. These are not, however, part of MGDB at the moment.

User involvement

The user community was not only involved during the user requirements phase, but also during the implementation of the software. Since the start of the implementation phase in the Spring of 1992, regular meetings between the contractor and the ESA project team at ESRIN, the ESA establishment in Italy, assured that the development of the software progressed well. Pre-releases of MGDB received from the contractor were presented at various workshops and conferences, such as COSPAR in Washington (1992) and the ELGRA annual meeting (1993), and during the data collection progress meetings. Comments on the user-interface were taken into account to improve user friendliness.

Documentation management

MGDB was developed in conjunction with three other systems needed for ESA administration. Common requirements between such diverse data as microgravity experiments and, for example, legal text, had been identified.

Moreover, the system will be used in ESA's Envisat-1 project, by the ESA team in Toulouse, in the Technical Information and Documentation Centre and in the Directorate of Telecommunications both at ESTEC.

For further information about accessing MGDB, contact:

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Three European astronauts are presently training at NASA's Johnson Space Center (JSC) in Houston. They are Claude Nicollier, Maurizio Cheli and Jean-François Clervoy. All three are Space Shuttle Mission Specialists, the astronauts who are responsible for on-board activities planning, resource management and experiment payload operations during a mission.

They are in different phases of their Mission Specialist training: Maurizio Cheli and Jean-François Clervoy have successfully completed their astronaut candidacy period and have recently entered the Advanced Training phase (Fig. 1), while Claude Nicollier is in Mission Training, preparing to be a crewmember of the Hubble Space Telescope First Servicing Mission in December (see related article, The Hubble Space Telescope First Servicing Mission, in this issue).

Three European astronauts are currently training as Space Shuttle Mission Specialists at NASA's Johnson Space Center in Houston. Two of the astronauts, Maurizio Cheli and Jean-François Clervoy, recently became members of NASA's 'astronaut pool' and have entered the Advanced Training phase. The third one, Claude Nicollier, is now preparing for the mission to service the Hubble Space Telescope in December.

The training of Maurizio Cheli and Jean-François Clervoy

Maurizio Cheli and Jean-François Clervoy were selected as European Astronaut Candidates by the European Astronauts Centre in May 1992. After a short period of introductory training at the Centre in Cologne, Germany, they joined NASA's Astronaut Candidate (ASCAN) Training Programme, Class of 1992. NASA had decided to give that class an international character and accepted five non-American candidates (two from ESA, two from the Canadian Space Agency and one from Japan's National Space Development Agency) in addition to 19 candidates from the U.S.

The ASCAN Training Programme lasts 12 months, and consists of 36 weeks of Basic Training, followed by 16 weeks of Advanced Training. Cheli and Clervoy began their Basic Training in August 1992.

The Basic Training programme

The Basic Training follows a progression, with each session building on the previous one and becoming increasingly specific to the Space Shuttle and its systems. Subjects covered include:

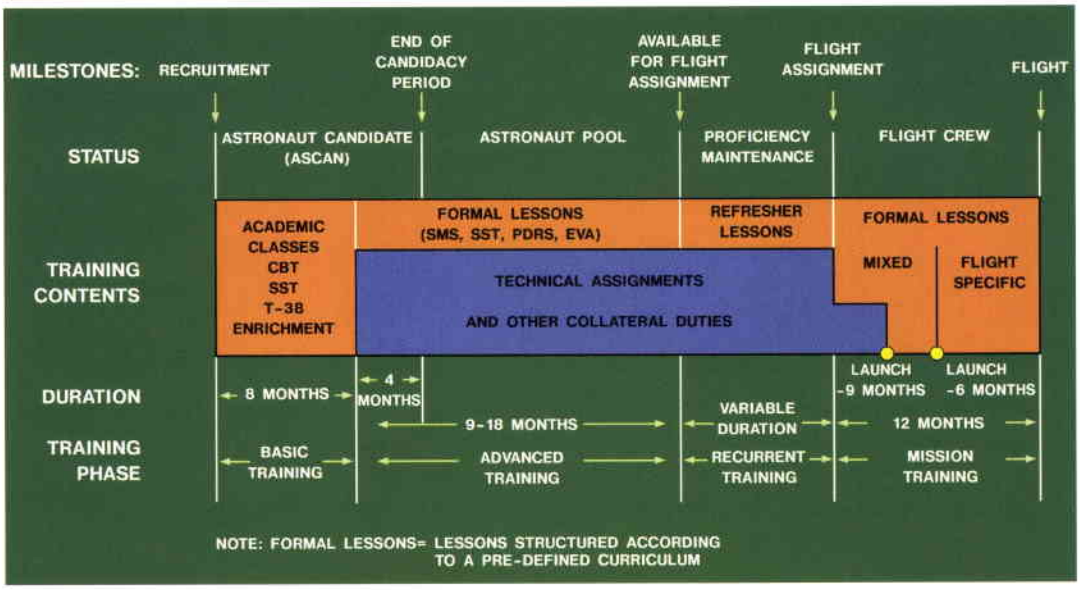

Figure 1. The phases of NASA's astronaut training programme, from recruitment to the first flight

Figure 2. Maurizio Cheli, with Japanese astronaut Koichi Wakata, during land survival training

— The flying of the T-38 supersonic jet trainer
— The fundamentals of the Space Shuttle system
— The functions and operations of the Shuttle's systems
— Operations and procedures for Shuttle missions
— Applied sciences and technologies.

In preparation for the T-38 flight activities, the candidates studied aircraft systems and navigation rules. They also participated in practical courses on land survival, water survival, emergency egress procedures and parasailing, which are conducted at various military bases. The candidates training to be Shuttle Pilots were then checked-out to fly in the front seat of the T-38, while the Mission Specialists were certified to fly in that aircraft as co-pilots.

Figure 3. Jean-François Clervoy preparing for familiarisation training with the T-38 jet at Ellington Field, near JSC

The core of the Basic Training programme, however, consists of training on the Shuttle systems and operations. The students tackled each system according to a phased approach: first self-study, then classroom lectures, and finally hands-on training. They first worked on their own, studying the basics of the system from a workbook. They then received a functional overview of each system through a computer-based lesson. This was followed by classroom lectures given by experts: Mission Operation staff described the use of each system, Engineering Directorate staff explained the rationale behind the design of each system, and finally experienced astronauts provided the 'user's point of view' on each system.

The classmembers then received hands-on training in a series of sessions on a simulator, the Single System Trainer (SST). The SST sessions were structured to gradually introduce the students to the system's operational environment, first by mastering its nominal operations, then by facing some significant malfunctions.

Other lectures given covered the astronaut's on-board tasks and the main procedures to be followed during the various phases of the flight. The science lectures spanned a wide range of space-oriented applications: from life sciences to material sciences and fluid physics, from Earth science to oceanography and Earth observation, from astronomy to planetary science and space physics. They were given in part by guest lecturers from universities and scientific institutions, and in part by other Mission Specialists with experience in space experimentation.

The candidate astronauts also participated in many other related and educational activities, such as:
— tours of the JSC Laboratories, other NASA centres, and contractor facilities
— swimming practice and obtaining their scuba diving qualifications
— coaching in media relations and public speaking
— presentations on spaceflight history, NASA's future programmes and the programmes of other space agencies
— discussions with former astronauts and other experts in the field.

The Advanced Training programme
Maurizio Cheli and Jean-François Clervoy, along with their classmates, began the Advanced Training in mid-April 1993. The Advanced Training period for NASA astronauts may last up to 18 months, the first four months of which is part of the ASCAN Training Programme (Fig. 1).

During this phase of training, the ASCANs continued the sessions on the SST simulator in order to maintain their knowledge of Shuttle systems. At the same time, they began new courses on Shuttle operations that are common to all flights (ascent, in-orbit flight, de-orbit/entry), and on common mission support systems, such as the Payload Deployment and Retrieval System (PDRS) which includes the robotic arm, and the Extra-Vehicular Activity (EVA) system. The lessons on Shuttle operations were administered to small groups of students in a fully functional replica of the Shuttle cockpit, called the Shuttle Mission Simulator, where students can learn to interact with many systems at the same time. The PDRS and EVA courses were given individually in various dedicated facilities. The students also undertook proficiency flights in the T-38 jet during this training phase.

In parallel with those activities, the candidates started to work on 'technical assignments'. These assignments, which are part of the 'collateral duties' of the astronauts not training for a specific mission, consist of part-time involvement in design and development work related to Shuttle systems and operations, with participation in meetings, working groups, tests and actual mission support activities. Jean-François Clervoy was assigned to the support of hardware and software development of the robotic arm, and Maurizio Cheli was assigned to the testing of the Shuttle flight software in the Shuttle Avionics Integration Laboratory. For both astronauts, other assignments in support of ESA programmes are foreseen in the near future.

New members of NASA's 'astronaut pool'
In total, at the end of the first year of training, each ASCAN had undergone about 750 hours of classroom instruction, about 100 hours in the Single System Trainer, about 40 hours in the Shuttle Mission Simulator, and around 100 hours of flying time.

During a ceremony at JSC's Astronaut Office on 3 August 1993, the Director of Flight Crew Operations awarded an official astronaut certification to each of the 24 candidates of the first international astronaut class. A few days later, during the annual NASA astronaut reunion, they each received the traditional astronaut pin.

Today, Maurizio Cheli and Jean-François Clervoy, while steadily progressing in their Advanced Training programme, are part of NASA's 'astronaut pool' and will soon be eligible to fly on future Shuttle missions. They can reasonably expect to receive an assignment in the course of the next year, for a flight in 1995-96. The experience that the two European astronauts, both young by astronaut standards, will have gained by then, both on ground and in space, will undoubtedly be useful for the future European crewed flight programme.

The training of Claude Nicollier
The third ESA astronaut training in Houston is Claude Nicollier. He has been stationed at JSC for several years, where he has gained a broad experience in Shuttle systems and operations. He flew on the STS-46 mission in August 1992, during which he played a prominent role in the deployment of ESA's Eureca satellite using the Shuttle's robotic arm.

Preparing for the HST Servicing Mission
A few months later, he was assigned to the STS-61 mission, which will undertake the in-orbit servicing of the Hubble Space Telescope (HST). The mission is expected to be launched in December.

That mission will require extensive use of the Shuttle's robotic arm, the Remote Manipulator System, not only to retrieve the huge instrument, place it in the cargo bay of the Shuttle for servicing and later deploy it to its final orbit, but also to move the mission specialists to the various servicing locations on the HST during five six-hour periods of EVA. Claude Nicollier will be the main operator of that arm, controlling it remotely

Figure 4. Claude Nicollier (right) at the controls of the Remote Manipulator System during a training session in JSC's Manipulator Development Facility. Ken Bowersox, the pilot for the mission, watches the manoeuvre on the monitor.

from within the Shuttle. He will also fulfil the role of Mission Specialist 2 (MS-2) for the mission. The MS-2 on a Shuttle mission has a function similar to that of the flight engineer on an aircraft: he cooperates with the commander and the pilot during some phases of the flight (such as ascent, descent and landing) by fulfilling a number of tasks relating to, for example, navigation, communication, and the execution of procedures.

Claude Nicollier began training for the STS-61 mission in January 1993 (at launch minus 11 months). He has been training in the two areas of expertise that are required for his role in the mission: as an MS-2 and as the operator of the robotic arm.

MS-2 training

The MS-2 training has mainly consisted of participating in simulations of selected phases of the flight, such as ascent and insertion into orbit, de-orbit and re-entry into the atmosphere, approach and landing, and rendez-vous and proximity operations.

The simulations have been performed mostly in the Shuttle Mission Simulators (Fixed Base or Motion Base), which can reproduce with great fidelity the functional interfaces between the crew and the various Shuttle subsystems, under normal operating conditions as well as under degraded conditions. Based on the instructional goals established, different types of simulation have been conducted ranging, for example, from nominal to contingency operations, or from skill improvement to proficiency maintenance. Claude Nicollier therefore has had the opportunity to further his knowledge of the Shuttle systems, to practise the flight procedures, and to exercise coordination and synergy with the other crewmembers (particularly the commander and the pilot), and especially in the presence of major malfunctions.

As the launch date approaches, the simulation scenarios have become increasingly realistic, evolving from standardised, flight-similar sequences to load-specific conditions in which the simulator has been driven by the actual flight software and has followed the actual mission model. Claude Nicollier has been spending up to 20 hours per week in the Shuttle Mission Simulators.

Training on the robotic arm

The training on the operation of the Remote Manipulator System has also been very demanding for Claude Nicollier. He has had to become very familiar with the configuration of the HST and its replacement hardware. This has also included a number of simulations.

The simulations have been conducted using different facilities, the characteristics of which complement each other in emphasising the various aspects of the training:

- the Manipulator Development Facility, for the realistic views of the payload layout
- the Shuttle Engineering Simulator for an accurate representation of the visual

Figure 5. As part of the virtual reality training for the mission, Claude Nicollier operates the virtual robotic arm from a workstation, while mission specialist Jeff Hoffman, wearing a tri-dimensional helmet and special gloves and working in simulated EVA conditions, 'sees' and 'touches' the telescope's hardware. Other STS-61 crewmembers observe the exercise (from left to right): Tom Akers (mission specialist), Ken Bowersox (pilot), Dick Covey (mission commander), and Kathy Thornton (mission specialist).

appearance of the arm and its dynamic behaviour
— the Shuttle Mission Simulator, for the capability to reproduce the arm malfunctions and the interaction with the Shuttle.

A tool that has been used for the first time in mission training is virtual reality simulation. That tool has been developed by the Automation and Robotic Division of JSC's Engineering Directorate, and includes three-dimensional models of the Space Shuttle 'Endeavour' and its robotic arm, as well as of the full HST. In the simulation, a Mission Specialist wearing a special helmet and gloves can 'see' and 'touch' the telescope hardware, as he is moved around by the virtual robotic arm controlled by Claude Nicollier from a computer workstation (Fig. 5). In this way, the two astronauts can refine the positioning of the arm and test the method of exchanging information that they will use during the delicate phases of the space work.

Other training

In order to validate the preliminary timelines and the procedures for the mission's EVAs, Claude Nicollier has also participated in tests at the Neutral Buoyancy Facilities at JSC and Marshall Space Flight Center, in which the servicing of the HST in weightlessness conditions has been simulated. During these simulations, he has perfected the voice protocols that he will use during the mission to communicate with the crewmembers engaged in the EVA work.

He has also undergone some training to familiarise himself with the photo and video equipment to be used in orbit, including the wide-format IMAX camera which will film the most spectacular scenes of the space work on the HST.

In this busy schedule, Claude Nicollier has also been undertaking the usual flight proficiency training required as a co-pilot of NASA's two trainer jets: the supersonic T-38 and a Cessna 'Citation 2', the teamwork-oriented Mission Specialist Training Aircraft.

The final training

In the weeks before the launch date, the mission training has been concentrating on so-called Joint Integrated Simulations, in which the flight crew, Mission Control Center staff, and HST science and engineering specialists rehearse together the most significant phases of the mission in a simulated, flight-like environment.

For Claude Nicollier, his fellow crewmembers and the ground teams, this is the final, valuable opportunity to test their preparation and to exercise the required coordination that will substantially increase the probability of success of their difficult mission.

Europe's Contribution to the Long Duration Exposure Facility (LDEF) Meteoroid and Debris Impact Analysis

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The near-Earth space is increasingly populated with operational spacecraft and space debris that could become a serious hasard to future space activities. To gain more information on small debris and meteoroids, surfaces and materials that have been exposed to the space environment are analysed after their return to ground. To further study that environment, NASA's Long Duration Exposure Facility (LDEF) spent 68 months in low Earth orbit. About 34 000 'impact records' have been identified; their size ranges from a few microns to several millimetres.

Several European laboratories and institutes are analysing the material and data collected. Some areas being investigated are the distribution and statistics of impacts, the morphology of impact features, the speed of impact and the chemical composition of the impacting particles, and the improvement of current debris and meteoroid models. The experience gained with LDEF is of paramount importance for the post-flight investigation of ESA's Eureca satellite and the solar arrays that will be returned from the Hubble Space Telescope in December.

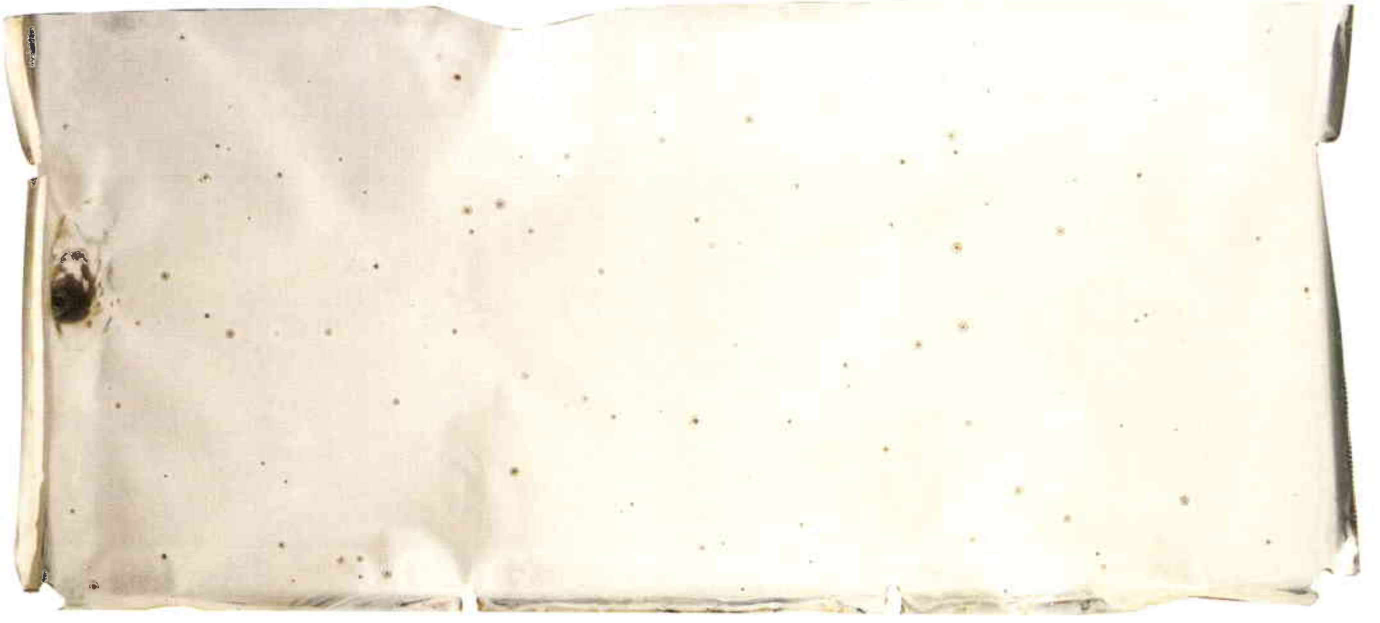
Space debris and meteoroids in near-Earth space

Spacecraft orbiting the Earth risk being hit by natural particles (meteoroids or cosmic dust) or by man-made objects (space debris). Space debris is any man-made and non-functional object in space regardless of whether it is still whole or whether it has fragmented. Thus, space debris includes satellites and rocket upper stages that have completed their mission, and fragments of satellites and rocket bodies. Currently the United States' space surveillance network is tracking more than 7300 satellites and orbiting debris larger than about 10 cm, using powerful radars and optical telescopes. About half of these objects are fragments from rocket and satellite breakups.

Space debris is an issue of great concern to all spacefaring nations. Although at present most space activities have only a small risk of being affected by debris, in the long term, a serious degradation of the near-Earth space environment could occur. Assuming that the current practices in space continue, independent investigations have concluded that the risk of collision will reach an unacceptable level, particularly in those regions that are most heavily used, for example, in the geostationary belt (36 000 km above the Earth's equator) and at altitudes between 900 and 1500 km.

Information on particles smaller than about 1 mm is obtained mostly through special detectors carried by spacecraft or through the analysis of material that has been exposed to the space environment. Analysis of the damage made on the surface of a returning spacecraft (Fig. 1 and 2) provides information on the meteoroid and micro-debris populations. These 'impact records' can also point to fragmentation events of satellites and rocket stages.

Before the space age began, information on the meteoroid population was obtained through the observation of meteors and meteorites and the analysis of the zodiacal light. (A 'meteoroid' is the particle in space while a 'meteor' is the phenomenon when a meteoroid is passing through the Earth's atmosphere. A meteoroid that survives the passage through the atmosphere and reaches the Earth's surface is known as a 'meteorite'.) The meteoroid population is the result of highly dynamical processes which include catastrophic collisions among particles, and of Poynting-Robertson drag, a decelerating force produced by the re-radiation of light from a particle in orbit around the Sun. The lifetime of meteoroids smaller than about 100 microns (cosmic dust) is limited by Poynting-Robertson drag to about 10^4 to 10^5 years. The dust spirals in toward the Sun and then evaporates. Very small, micron-sized meteoroids (the beta-meteoroids) are expelled from the solar system on hyperbolic trajectories. The lifetime



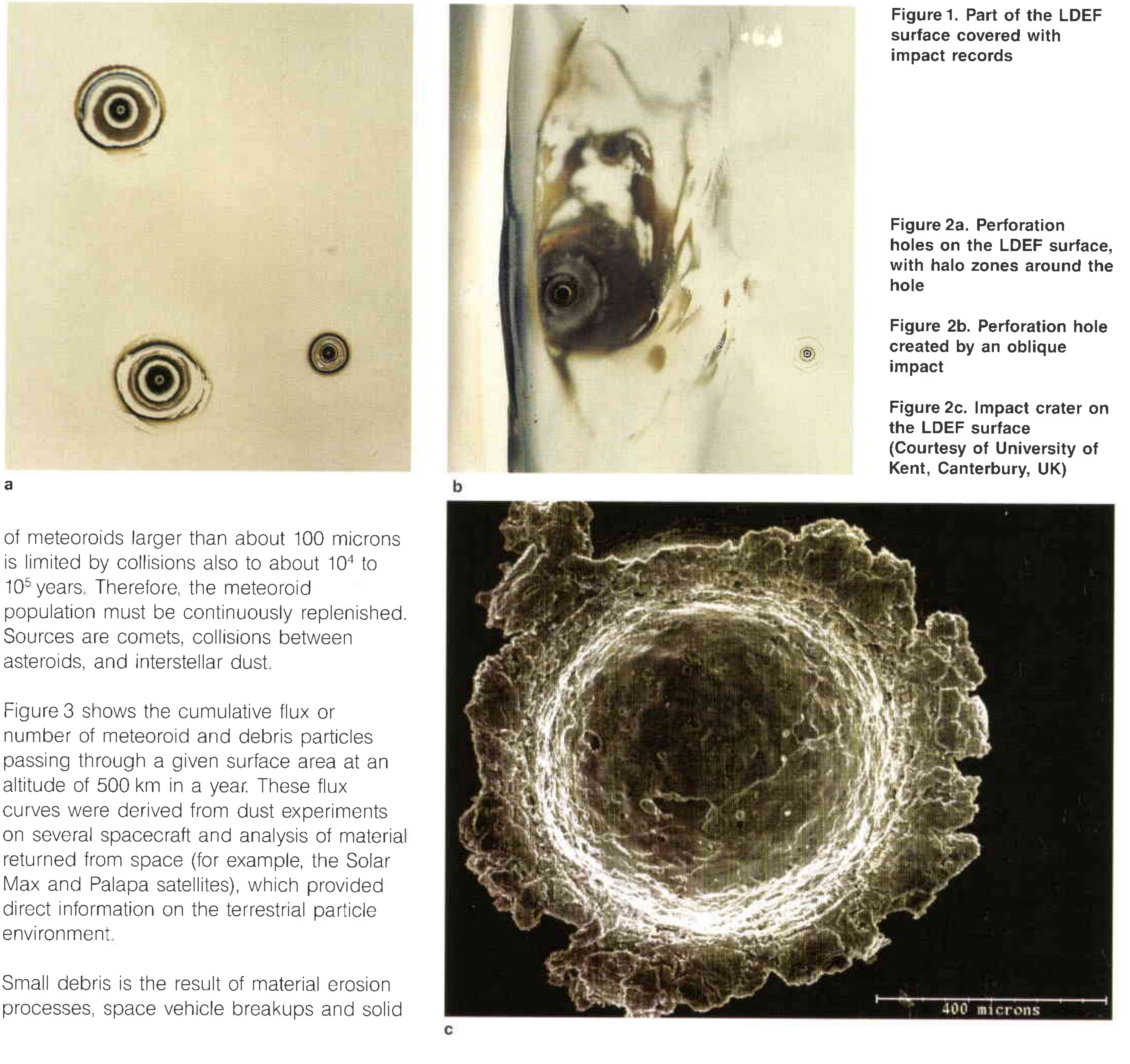


Figure 1. Part of the LDEF surface covered with impact records

Figure 2a. Perforation holes on the LDEF surface, with halo zones around the hole

Figure 2b. Perforation hole created by an oblique impact

Figure 2c. Impact crater on the LDEF surface (Courtesy of University of Kent, Canterbury, UK)

of meteoroids larger than about 100 microns is limited by collisions also to about 10^4 to 10^5 years. Therefore, the meteoroid population must be continuously replenished. Sources are comets, collisions between asteroids, and interstellar dust.

Figure 3 shows the cumulative flux or number of meteoroid and debris particles passing through a given surface area at an altitude of 500 km in a year. These flux curves were derived from dust experiments on several spacecraft and analysis of material returned from space (for example, the Solar Max and Palapa satellites), which provided direct information on the terrestrial particle environment.

Small debris is the result of material erosion processes, space vehicle breakups and solid

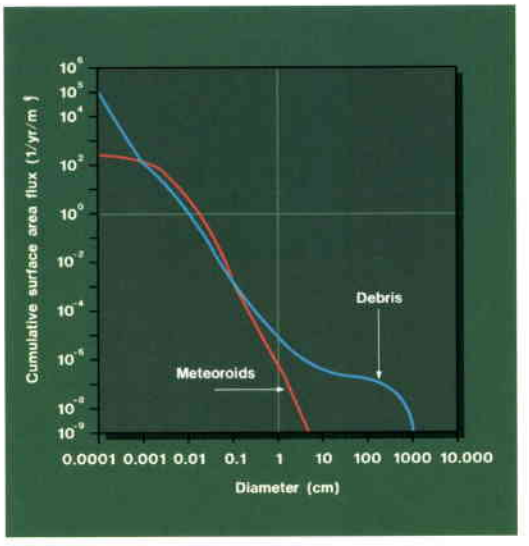


Figure 3. Cumulative flux of meteoroids and debris passing through an area of 1 m² in near-Earth space in a year, at an altitude of 500 km. The flux of debris exceeds the flux of meteoroids except for particles with a diameter between 0.02 and 0.3 mm.

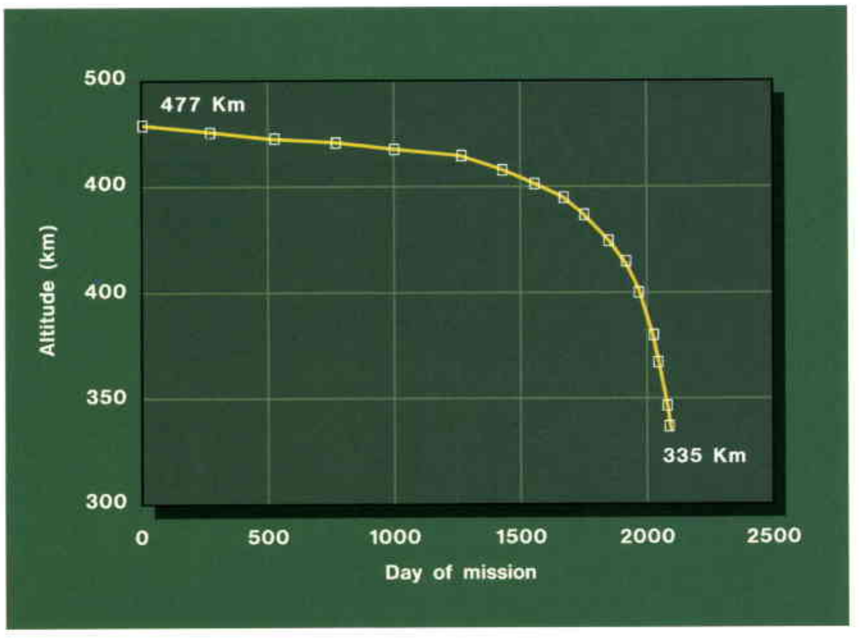


Figure 4. The LDEF's altitude during the mission. The decrease is due to atmospheric drag, which reached particularly high values during the solar maximum of 1990 (high solar activity increases atmospheric density). The number of impacts received during a mission is related to the spacecraft's altitude.

motor firing. Since 1957, more than 110 breakups have been observed. Most of them are explosions of rocket upper stages which can generate several hundred fragments that are observable from ground. The most significant breakups since October 1990 are listed in Table 1.

The LDEF spacecraft

NASA's Long Duration Exposure Facility (LDEF) was deployed on 7 April 1984 by STS-41C in an almost circular orbit at an altitude of 477 km and an inclination of 28.5 degrees. It had a surface area of 150 m² that was exposed to the environment in the low Earth orbit (LEO) for a long period. One of its purposes was to gather *in situ* measurements of the meteoroid and debris environment in LEO. It carried 57 experiments covering four areas:
— materials, coatings and thermal systems
— power and propulsion
— science
— electronics and optics.

Although it was planned to retrieve the LDEF after ten months, its retrieval was postponed because of the Space Shuttle 'Challenger' (STS-51L) accident. It was eventually recovered 68 months after launch, on 12 January 1990. This delay provided the opportunity to gather much more data than had been planned. At the time of retrieval, the orbital altitude had decreased to 335 km (Fig. 4).

The LDEF spacecraft was an open-grid, 12-sided, cylindrical structure (Fig. 5). It was 9.1 m long and 4.3 m in diameter. A series of rectangular trays used for mounting experiment hardware was attached to the

International designation	Object	Country	Launch date	Fragmentation date	Apogee altitude/ perigee altitude (km)	Objects tracked (detected)
1990 – 81 D	Long March 4	China	3 September 90	4 October 90	895/876	81
1990 – 105 A	DMSP 2 – 5	USA	1990	1 December 90	850/610	> 50
1983 – 127 H	Upper stage / SL-12	USSR	1983	3 February 91	18962/332	12
1991 – 09 J	SL-8 / 2nd stage	USSR	1991	5 March 91	1720/1460	> 50
1975 – 052 B	Delta 2nd stage	USA	1975	May 91	1100	> 200
1991 – 71 A	Kosmos 2163	USSR	1991	6 December 91	214/133	9 (20 – 30)
1985 – 118 L	SL-12	USSR	1985	29 December 91	18900/700	26
1968 – 81 E	Titan 3 C Transtage	USA	1968	21 February 92	35800/35100	20
1984 – 106 F	SL-12	CIS	1984	5 September 92	848/830	62
1989 – 04 F	SL-12	CIS	1989	17/18 December 92	18632/185	75 – 100
1992 – 93 B	SL-16	CIS	1992	26 December 92	854/849	204
1993 – 16 B	SL-16	CIS	1993	28 March 93	850/848	20 – 25

Table 1. Breakups that have occurred since October 1990 and have created more than 10 trackable fragments. Since 1961, 116 breakups have occurred: 42 were propulsion-related, 44 deliberate, and 26 of unknown cause. The total number of fragments generated is not known since only large pieces can be tracked from ground. There were no major breakups between May 1988 and September 1990.

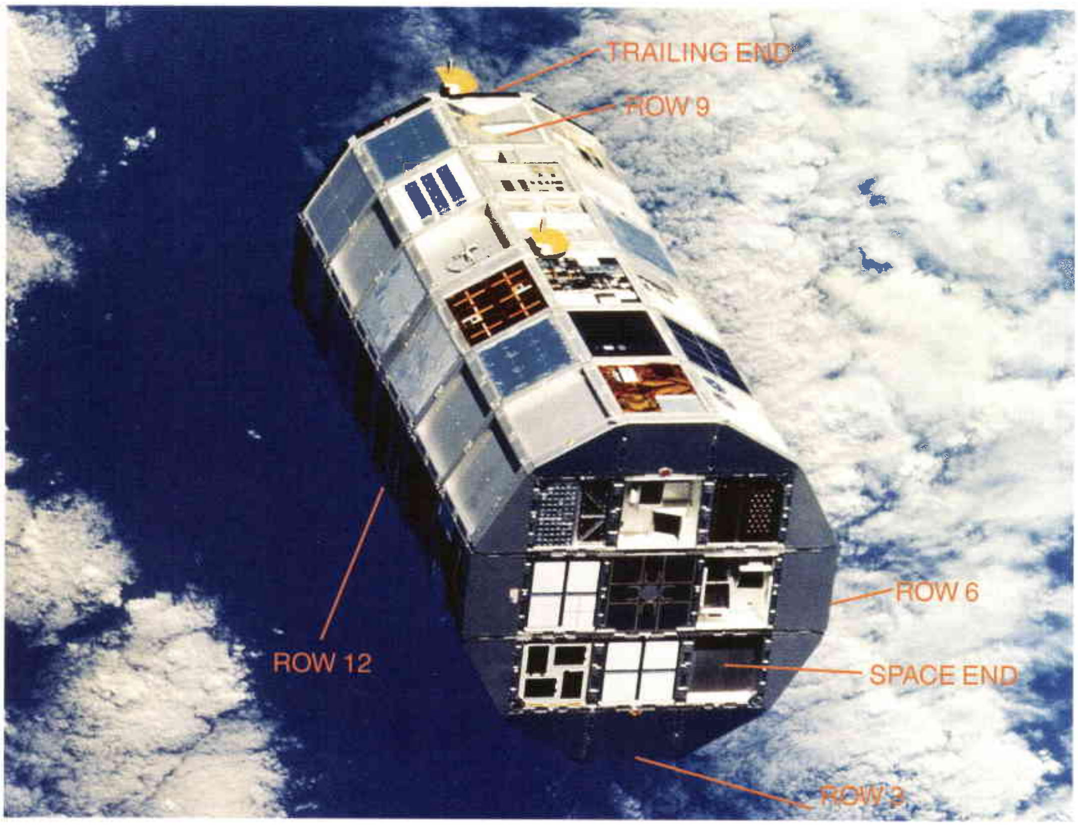


Figure 5. The LDEF spacecraft

structure. Since the LDEF was gravity-gradient stabilised (with the longitudinal axis pointing toward the centre of the Earth), surface elements were fixed relative to the spacecraft's velocity vector. Magnetic actuators controlled the rotation around the longitudinal axis. The nominal leading surface was the east face (row 9), and the nominal trailing surface was the west face (row 3). Thus, studies of the LDEF's impact records will provide directional resolution of the flux of meteoroids and space debris particles.

Expected impacts based on standard meteoroid and debris models

Depending on the velocity distributions of meteoroids, it was expected that the leading surface of the LDEF would receive 12 to 30 times more impacts from particles with a diameter of 0.5 mm than the trailing surface would receive. Analyses based on state-of-the-art debris and meteoroid reference models predicted that the LDEF would receive about 4000 impacts by particles larger than 0.1 mm and about 3 impacts by particles larger than 1 mm.

European space debris and meteoroid experiments on LDEF

The design of space debris and meteoroid experiments is inherently difficult. Ideally, a scientist would like to measure the number of impacts, the impact velocity (magnitude and direction), and the mass, density and chemical composition of the impacting particle. However, because of the high velocity at the time of impact, the impacting particles are physically destroyed during the crater formation process and become mixed with the target material. Identification of the major components may still be possible but information on the velocity, incident direction and particle density is generally difficult to ascertain.

Table 2. European experiments on LDEF (or with European involvement) relating to meteoroids and debris

Experiment	Prime Investigator	Remark
French Cooperative Payload (Frecopa)	J.-C. Mandeville CERT/ONERA, Toulouse (France) and others	
Chemical and isotopic measurements of micrometeoroids by secondary ion mass spectrometry (SIMS)	E. Zinner Washington University St. Louis, Missouri (USA)	The SIMS measurements were done in collaboration with MPI für Kernphysik, Heidelberg (E.K. Jessberger)
Multiple-foil micro-abrasion package (MAP)	J.A.M. McDonnell University of Kent Canterbury (UK)	
A high resolution study of ultra-heavy cosmic ray nuclei (UHCRE)	D. O'Sullivan Dublin Institute for Advanced Studies Dublin (Ireland)	The thermal blankets of the UHCRE experiment provide an impact record of meteoroids and debris

European laboratories and institutes provided or contributed to three of the impact-analysis experiments on board the LDEF (Table 2). Although a fourth experiment had a very different objective, the impact records that it received provided important data for impact analysis.

The French Cooperative Payload (Frecopa) experiment
One of the purposes of the Frecopa experiment was to determine the number of impacts, and the size and chemical composition of the impacting cosmic dust and debris particles.

Two entirely passive experiments for the detection of micrometeoroids and debris were conducted. They were located on the trailing surface (row 3) of the spacecraft. A total area of about 2000 cm^2 was exposed to the space environment. In one experiment, a set of glass and metal samples (Al, Au, Cu, W, stainless steel) was used. In the other, multi-layer thin foil detectors were used.

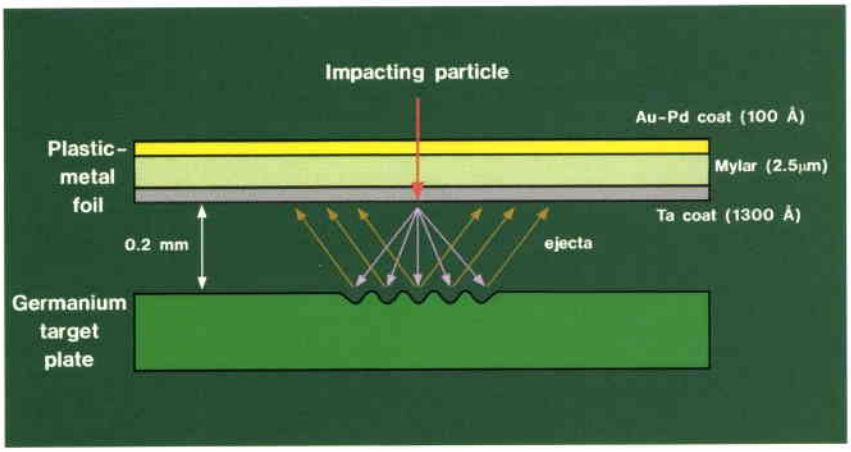


Figure 6. The capture-cell experiment used to determine the chemical and isotopic composition of the impactor. A small particle penetrates the foil at high velocity and may be disrupted in the process, spreading a shower of debris. This shower hits the target plate, is further disrupted, melts and is vapourised. The projectile material from the impact zone recondenses on the backside of the foil and on other surfaces.

In addition to these dedicated experiments, a large variety of materials placed on the same tray (8500 cm^2) was exposed to the bombardment of microparticles while the LDEF was in orbit and thus provide additional data.

Chemical and isotopic measurements of micrometeoroids by secondary ion mass spectrometry
This joint US-German experiment was a capture-cell type experiment. The principle behind it is shown in Figure 6.

This experiment consisted of 237 capture cells, each measuring 8.6 x 9.4 cm, located on three different rows. The target material (germanium wafers) was of very high purity, which is essential for the determination of the composition of the deposit. After the experiment returned, the deposit left in the capture cell would be analysed to determine its chemical composition.

After the return of the LDEF, however, it was found that all capture cells on the leading-edge tray had lost their plastic-metal foil that covered the target plate, due to atomic oxygen erosion. Only 12 of the 77 cells on the trailing edge had retained theirs. Thus, some of the deposits from impacting particles were lost.

The Multiple-Foil Micro-Abrasion Package (MAP)
The MAP experiment is also a capture-cell type experiment. Each MAP detector consists of two foils and a pure, polished stop plate to catch fragments of impacting particles. The capture-cell system was formed between the top and the second foil surface. Aluminium foils with a thickness of 1.5 to 30 microns were used. Rolled brass with a nominal thickness of 5 microns was also flown to permit chemical discrimination of residues from aluminium-bearing space debris.

The MAP experiment provides information on impactor velocity, density, angle of incidence, and chemical composition. The MAP detectors were deployed on the leading surface (row 9), the trailing surface (row 3), and rows 6 and 12 as well as on the space-pointing face.

The Ultra High Cosmic Ray Experiment (UHCRE)
The purpose of this fourth experiment was not impact analysis, however, the 18 m^2 of thermal blankets and the trays used in the experiment were covered with a large number of impact records of various sizes that were used for impact analysis. The largest crater on the thermal blankets has a diameter of 2.5 mm.

First results of visual inspection
After the LDEF returned to ground, the larger impact records were documented in great detail. The size, type, location and additional characteristics of all impact records larger than about 0.3 mm were registered with digitised, stereo, colour imaging. About 5000 impact records were registered; they consist of impact craters and penetration holes larger than 0.5 mm in diameter for thick surfaces, or larger than 0.3 mm in diameter for thinner, blanket-type material.

A first survey identified a total of about 34 000 impact records on all space-exposed surfaces, including 3119 records larger than

0.5 mm on the entire vehicle. The largest impact record identified was a 5.25 mm diameter crater located on a frame facing the direction of velocity.

These figures agree roughly with the number of expected impacts.

First results of detailed analysis
After the visual inspection of the LDEF, a more detailed analysis of the impact records began. European investigators specifically examined impact statistics, the morphology of impact features and the chemical composition of the impacting material.

Ratio of particle size to crater diameter
In an effort to understand the nature and characteristics of the impact records, an experimental simulation was undertaken. Glass, aluminium, and iron projectiles with masses ranging from about 30 nanograms to several milligrams, were shot at spare foils from the UHCRE. The shots were performed using a light-gas gun (by Ernst-Mach Institute, Germany) and plasma accelerators (by TU Munich, Germany). Impact velocities ranged from about 3 to 13 km/s.

Characteristic impact craters and perforation holes were produced. Their sizes and morphologies were compared to respective projectile impact parameters obtained from the LDEF. The same crater characteristics were obtained in the simulation as on the LDEF. The ratio of the diameter of the crater to impacting particle size was determined for a range of impact velocities. Depending on the impact velocity, the ratio varies between about 1.5 and 5.

For impacts at hypervelocity (more than several km/s), the volume of the craters formed is proportional to the kinetic energy of the projectile.

'Halo zones' around perforation holes, as were observed on the exposed LDEF foils (Fig. 2a), were also obtained during the simulation. They were found to be delamination effects within the layers of foil, caused by the propagation of impact shock waves and the subsequent effect of atomic oxygen.

Chemical composition
The chemical composition of an impacting particle is difficult to determine because, due to the high impact speed, little of the material survives unaltered. The particle vapourises and then re-condenses on the surrounding surfaces. Although capture-cell experiments were designed to allow the identification of the composition of the impacting particles, the layer of impact debris collected on the surfaces is too thin to be seen using either an optical or a scanning electron microscope.

Using Secondary Ion Mass Spectrometry (SIMS), a technique that is sufficiently sensitive to analyse the deposits that are only 0.5 to 5 monolayers thick, 24 impact records on germanium from trailing-edge capture cells that had lost their plastic-metal foil were analysed. Histograms for elemental ratios were established and compared with interplanetary dust particles. Magnesium was found to be the most abundant element compared to iron, aluminium, calcium, and titanium. Impact records that contain primarily aluminium were not detected.

The first results obtained from the trailing capture cells are:
- There are large variations of elemental ratios within a given impact record, indicating that the projectile had a heterogeneous chemical composition.
- At least 75% of the impact records analysed appear to be caused by micrometeoroids.
- Comparison with simulation impact records indicates that most LDEF impact records analysed were caused by small (less than 10 microns) projectiles.

Morphology of impact craters and impact statistics
The impact records observed showed similar features: approximately circular symmetry, evidence of melting and fusion, and a raised circumferential lip (not on thermal covers) (Fig. 2c).

The MAP experiment showed that, with aluminium foils with a thickness of 5 microns or more, the penetration distributions differ significantly depending on the face on which the detector was located. For foils with a thickness of 20 microns or more, natural particles penetrate more often, yielding fluxes compatible with a geocentric velocity of approximately 17.4 km/s. For thinner foils (located on the leading surface and on the north and south faces), orbital particles exceed the natural component by about a factor of four (5 microfoils). Although in terrestrially-bound orbits, the origin of particles has not yet been established exclusively as space debris.

A comparison of the particle flux from the Russian Mir spacecraft and the LDEF is shown in Figure 7. On the LDEF, the test area was facing the direction opposite the direction of motion (or trailing edge and therefore would receive fewer impacts), while on Mir, the experiment surface was pointing in different directions. The data from the LDEF are in agreement with current models (although there is very little other data available for crater diameters of less than 10 microns). The flux figures diverge significantly for crater diameters of less than 40 microns and the difference is most marked for the smallest diameters (0.5 micron).

Other results
Scientists in the U.S. made an important discovery with another LDEF experiment, the Interplanetary Dust Experiment (IDE), which was designed to detect impacts of extra-terrestrial particles and orbital debris for

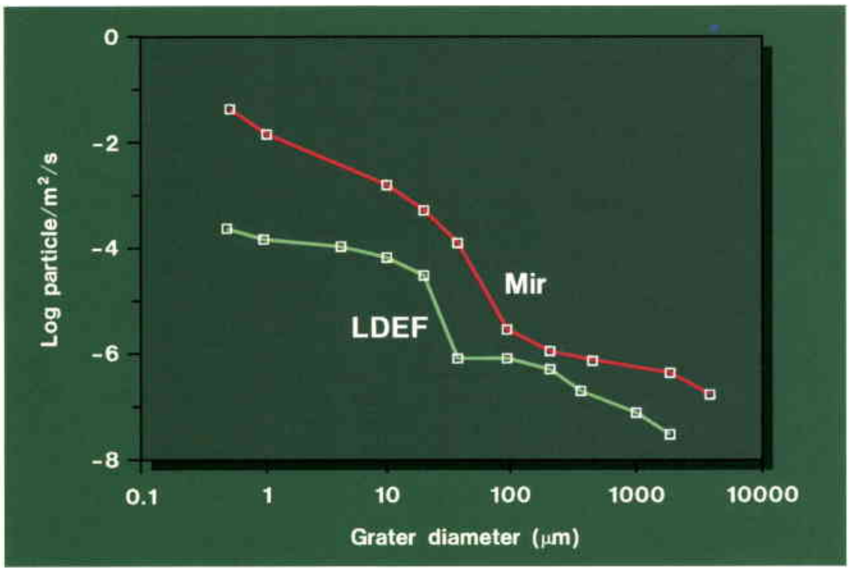


Figure 7. Comparison of particle flux data from the Russian Mir and the LDEF missions

particles ranging in size from 0.2 to 100 microns. The IDE occupied portions of six trays, one each on the leading and trailing surfaces, the Earth and space ends, and the north- and south-facing rows. The time of each impact was recorded during the first 348 days in orbit (with a resolution of about 13 seconds).

The IDE showed that impacts often occurred in bursts typically lasting 3 to 5 minutes. Such spatially and temporarily confined events could result from the impacts from a fragmentation on a Molniya-type orbit. Molniya orbits have a 12-hour period, have an eccentricity near 0.72 and are of high inclination (63.4 degrees).

Conclusion
The LDEF has contributed unique, *in situ* measurements and data to the knowledge of the natural and man-made sub-millimetre particle population in near-Earth space. From the analyses carried out to date, the following conclusions can be drawn:

— In general, the number of particle impacts received agrees largely with current models. As expected, there were more impacts on the leading surfaces than on the trailing ones. However, the number of impacts on trailing edges is significantly higher than expected.
— The higher than expected number of impacts on the trailing side points to the existence of debris particles in elliptical orbits, e.g. geostationary transfer orbits (GTOs). This indicates a deficiency in current debris models which do not take into account fragmentations in GTO. It also means that spacecraft in LEO that require protection also need shielding on rear surfaces.
— The LDEF experiments show that impacts often occurred in bursts typically lasting 3 to 5 minutes. Such spatially and temporarily confined events have a similar signature as one would get from a fragmentation occurring in a Molniya-type orbit.
— The LDEF investigations regarding meteoroid and debris impacts provide relevant experience for the post-flight investigations of the European Retrievable Carrier (Eureca) and the solar arrays to be returned from the Hubble Space Telescope (see photos of impact records on Eureca in the 'In Brief' section of this issue).

The Habitability Mini-Laboratory: Testing the Tools of Space Habitat Architecture

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Living in the closed, confined environment of a space station for a long period and under microgravity conditions, crew members can encounter problems of a physiological and also a psychological nature. The architecture of their living quarters can greatly influence their well-being and their efficiency.

Simulation of a proposed architecture and of human movement within that architecture is the most effective way to evaluate the design. Two simulation tools, Computer-Aided Design (CAD) software tools and a mock-up on a smaller scale, were used to 'construct' several proposed architectures. Those models were then evaluated to determine the investigation methods that should be used in future architectural development projects.

Introduction

Living in the closed, confined environment of a space station for a long period and under the unusual conditions of microgravity, introduces crew members to a wide range of problems, which are not only of a physiological but also of a psychological nature. The architecture of their living quarters, the so-called habitation module, in which they will eat, sleep, relax and exercise, can influence the crew's well-being and efficiency. Simulation of the architecture and of human movement within that architecture is the most effective way to evaluate the proposed design of the habitation module.

For the past few years, ESA has been studying how to best support the long-duration presence of humans in space, in preparation for future crewed space missions in low Earth orbit (LEO). As part of that work, the Long-Term Programme Office (LTPO) of ESA's Directorate of Space Station and Microgravity has defined the required habitability technologies in its European Manned Space Infrastructure (EMSI), which has been widely used as a reference scenario.

ESTEC's Life Support and Habitability Section has carried out a series of in-house studies on the architecture of space habitats both in LEO and on the Moon and planetary surfaces. The work has included the evaluation of simulation tools that are used in architectural design. In that study, referred to as the Habitability Mini-Laboratory, users compared habitation modules created using Computer-Aided Design (CAD) software tools and a reduced-scale mock-up of the habitation module, on the basis of such parameters as ergonomy and psychological acceptability of the design. The objective was to identify the investigation methods based on simulation tools that should be used to evaluate the design of space habitation modules, including the definition of investigation criteria and test methods, and the assessment of the reliability of results.

Habitation module configurations

There are two basic designs of a habitation module for a space station in LEO (Fig. 1a):

— a vertical-axis cylinder (the typical Skylab configuration)
— a horizontal-axis cylinder (the typical Columbus Attached Laboratory/Space Station Freedom and Mir configuration).

In turn, the layout of the habitation module can be classified according to two main criteria:

— the orientation of the interior design, for example, whether it is oriented in an Earth-like way (Fig. 1b), or whether all of the module's 'rooms' or decks are oriented in one or different ways
— the degree of flexibility and reconfigurability of the internal structure and equipment, i.e. whether the components of the structure and the equipment can be used for more than one task or whether they can be easily reconfigured to be used for another task.

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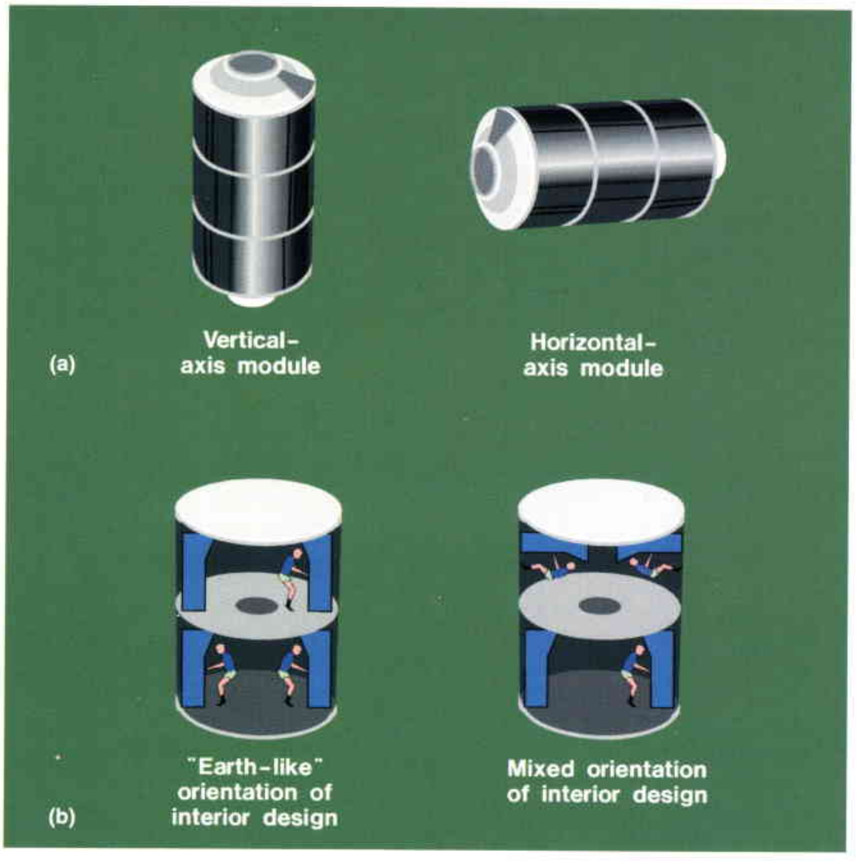


Figure 1. Basic designs of a habitation module for a space station in LEO

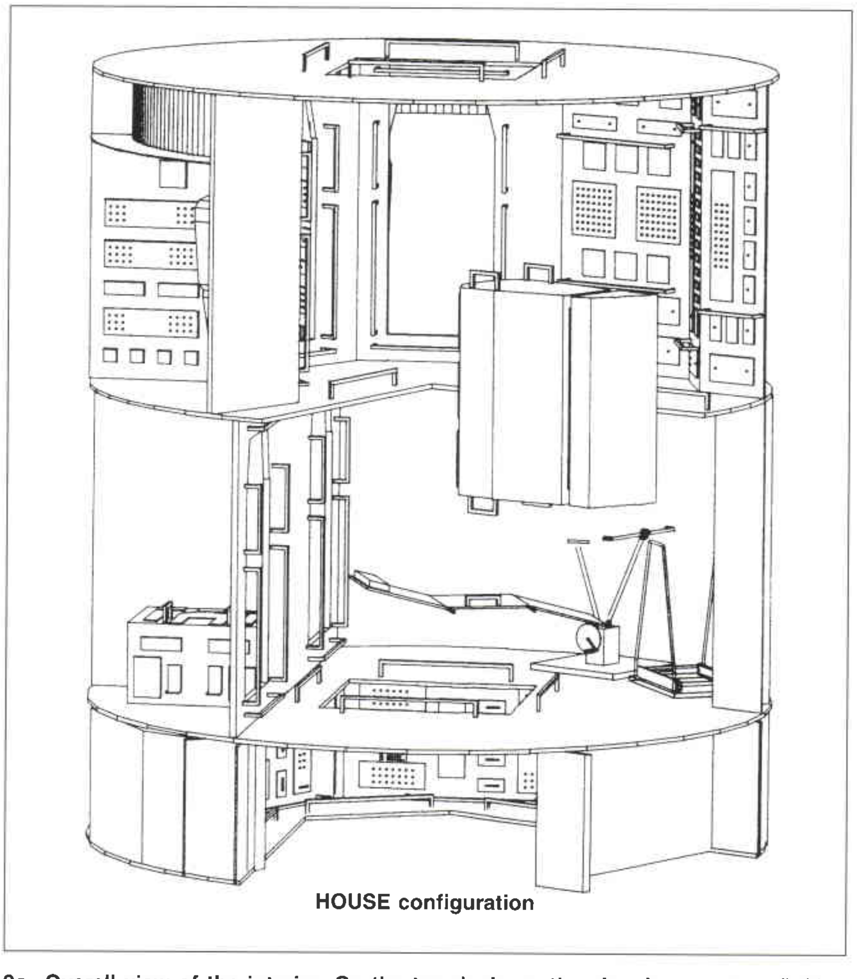
The Habitability Mini-Laboratory study

The architectural projects used

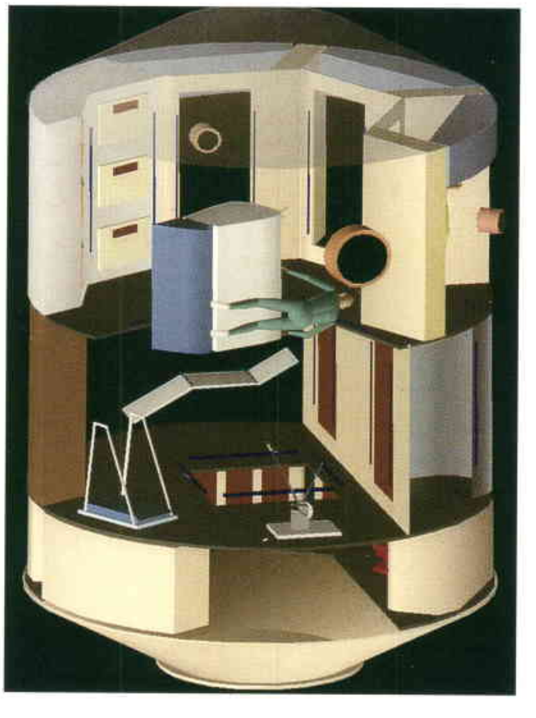
Three proposed designs for the habitation module that had been developed in Europe and submitted to ESA, were selected for this study, notably because they were the most elaborated, i.e. more detailed drawings and specifications for equipment were available. Each design was based on the European Space Station reference configuration for a LEO base as specified by EMSI. That configuration assumes a crew of three or four members permanently at the station for a period of three to six months.

The projects used are:

- HOUSE: a vertical-axis cylinder with a multi-oriented layout (the orientation differs from one deck to another, and the equipment is multi-oriented), and with partial modularity (at the deck-level only) (Fig. 2)
- HABEMSI: a vertical-axis cylinder with an Earth-like oriented layout and equipment installation, and a low degree of modularity (the decks are of different heights) and flexibility (Fig. 3)

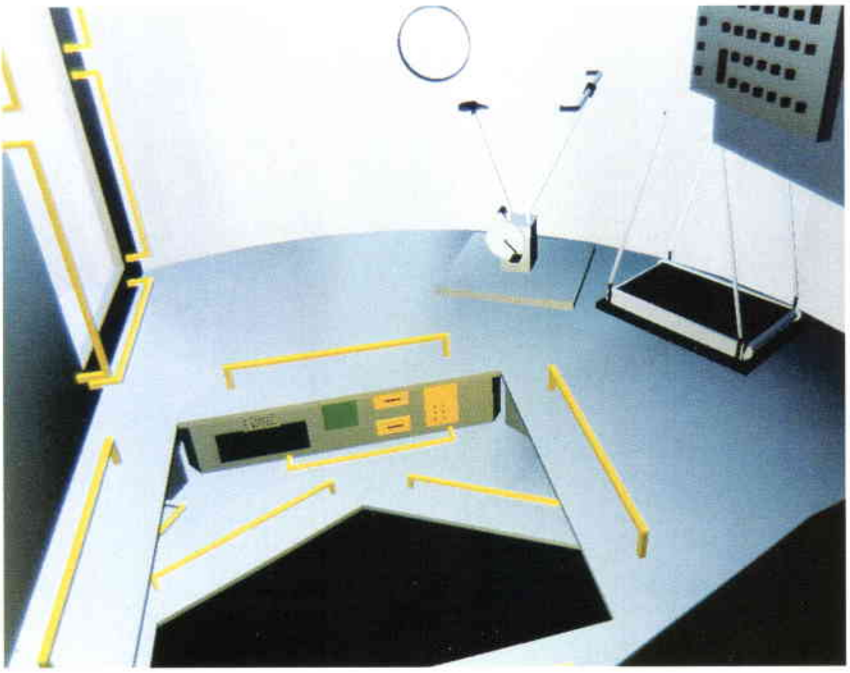


2a. Overall view of the interior. On the top deck are the sleeping quarters (left) and the galley (right). On the middle deck are the exercise facilities (right) and the hygiene facilities (left). Supplies and the life support systems are on the bottom deck.



2b. A DYNAMAN view of the configuration. The astronaut is at the wardroom table, which is oriented in a different way than the surrounding environment.

2c. The galley and the sleeping quarters on the top deck of the mock-up

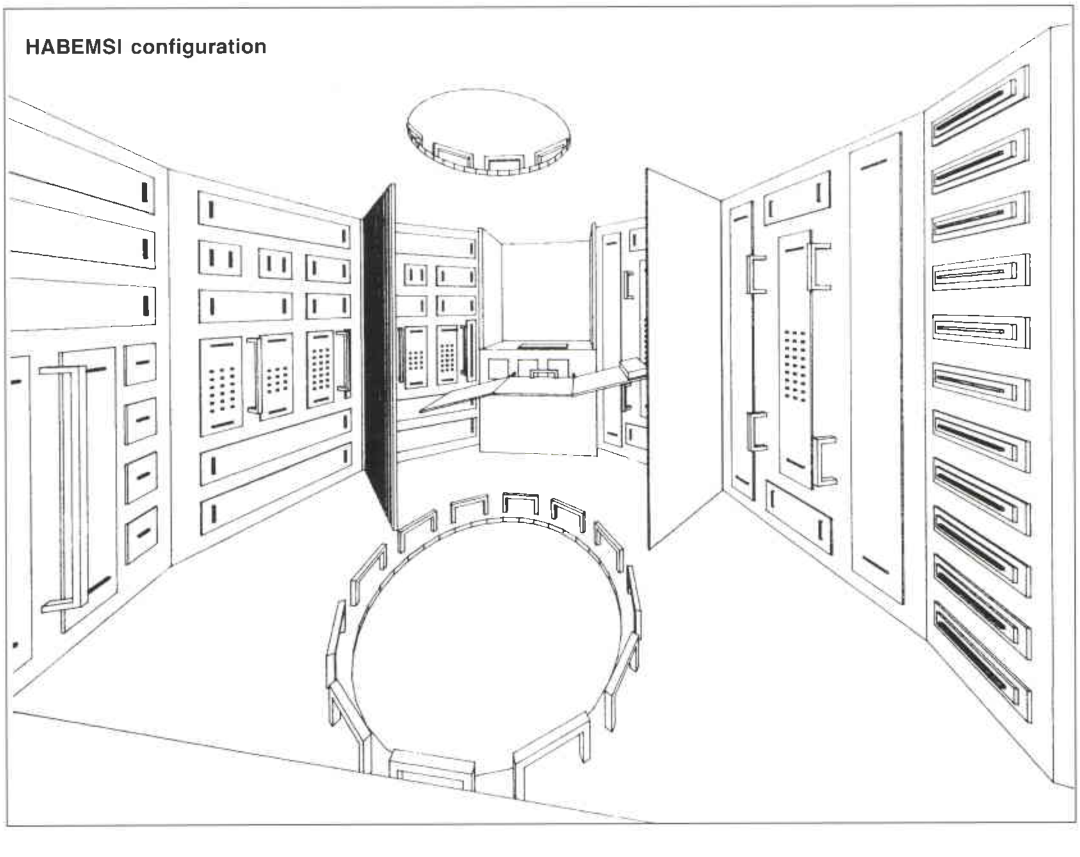


2d. A STAR view of the middle deck, with a rack on the bottom deck visible through the passageway

— ENSAD: a vertical-axis cylinder, with decks in an asymmetrical configuration, an Earth-like orientation, equipment arranged around 'stand-off' columns, and a high degree of modularity and flexibility (Fig. 4).

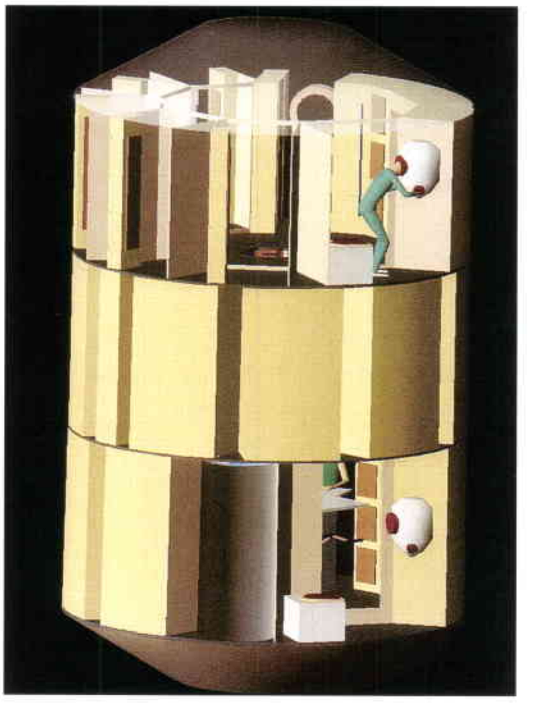
The simulation tools used

In an architectural project, simulation is a continuous interactive process. Throughout the development of the module, the design is being evaluated continuously to obtain meaningful feedback from the user community and thereby optimise the design. For a space application, the establishment of a suitable simulation process is necessary in order to assess the impact of microgravity.



3a. The middle deck, with the medical facilities (back) and the galley, life support systems and supply storage racks (front)

3b. A STAR view of the middle deck, showing the medical facilities (left) and the exercise ergometer (right). Part of the lower deck (the wardroom table) can be seen through the passageway in the centre of the floor.



3c. A DYNAMAN view of the configuration. On the top deck are the sleeping quarters and hygiene facilities. The middle deck is occupied by storage racks (not visible) while additional hygiene facilities and the wardroom table are on the lower deck.

Two CAD software codes were selected to model the architectural projects:

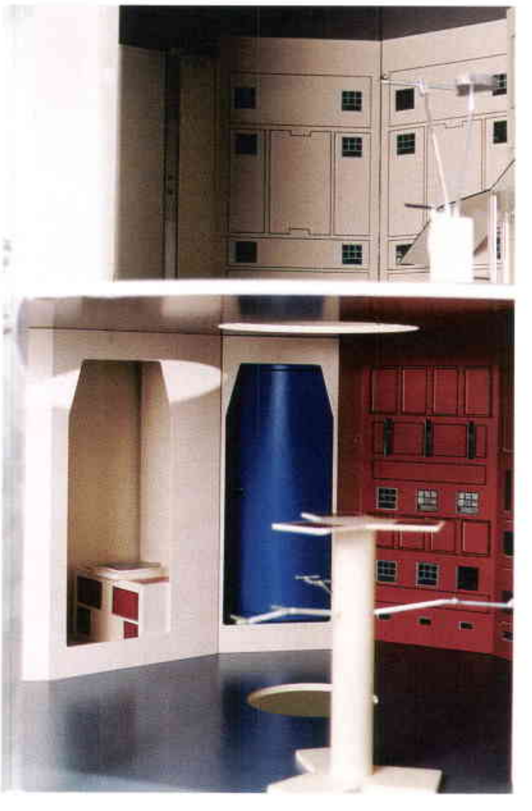
- DYNAMAN, a CAD software for modelling human motion behaviour (Fig. 2b, 3c)
- STAR Architecture UX, a CAD software for architectural design (Fig. 2d, 3b, 4b, 4d).

A mock-up of the module at a reduced scale was also constructed (Fig. 2c, 3d, 4c).

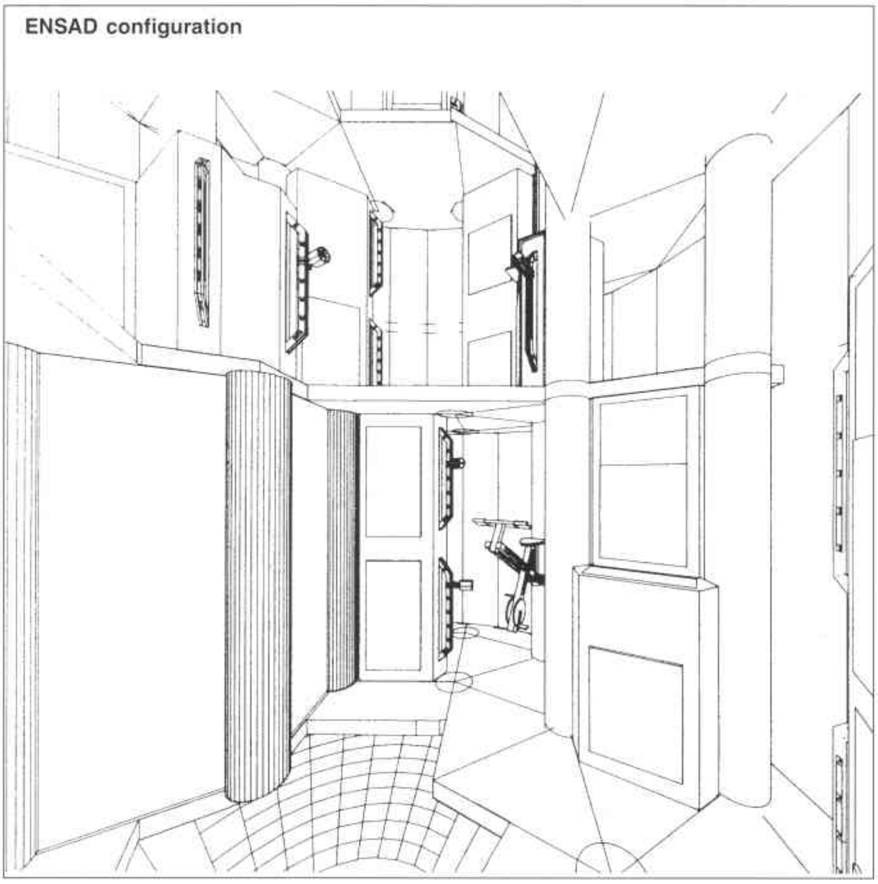
The purpose

The Habitability Mini-Laboratory was intended to be a preliminary step toward the eventual implementation of a full-scale mock-up of the habitation module. The Mini-Laboratory offers great advantages in terms of cost and flexibility. Opportunities to evaluate space habitat architectural projects in actual size and real environment (particularly microgravity, confinement and isolation) are rare and expensive and do not allow sufficient flexibility.

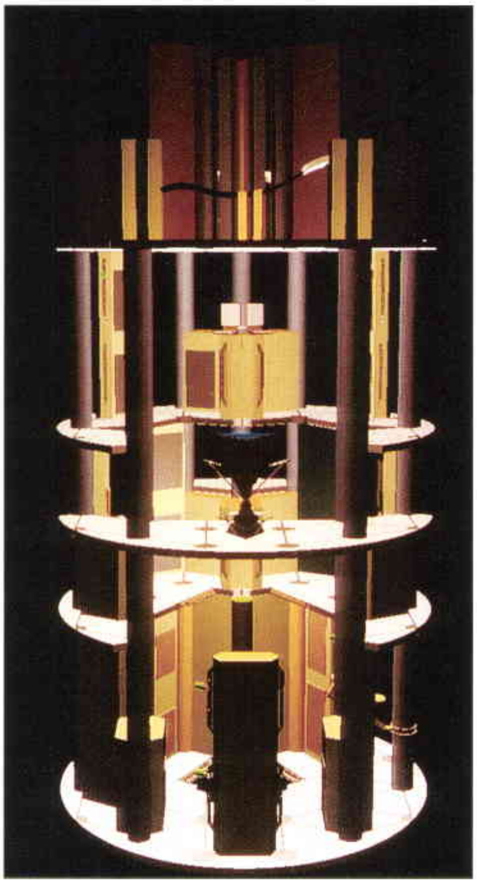
Computer and reduced-scale simulation also allows microgravity conditions to be considered more effectively than in a full-scale mock-up. To simulate microgravity, this full-scale mock-up could eventually be submerged into a neutral buoyancy facility, but even this solution would have a limited value since hydrodynamic forces would constrain motion.



3d. A view of the middle and lower decks of the mock-up. On the middle deck, the exercise equipment is shown. On the lower deck, the wardroom table (foreground) and the galley (in brown), shower booth (in blue) and toilet (left) are shown.



4a. A central perspective view, showing the symmetrical layout of half-decks and equipment racks arranged around 'stand-off' columns



4b. A STAR view of the module showing from top to bottom: sleeping quarters, crew workstations, the wardroom table, and hygiene and exercise facilities

4c. A view of the mock-up, with the wardroom table on the top half-deck, and the exercise ergometer on the bottom deck

4d. A STAR view down the centre line, showing the modular construction of the half-decks. A portable workstation (keyboard at the top left) gives an idea of the scale.

The experimental results of the Mini-Laboratory study were based on the evaluation of motion sequences obtained with the simulation tools. Two types of sequences were produced:
- a motion sequence based on a crew member's daily routine, for example, getting out of bed, washing and preparing a meal
- a motion sequence simulating a visit to the module.

Other investigation support methods, such as still pictures or slides, would also have been advantageous. However, it was decided to limit the study to one type of presentation aid because of the need to obtain statistically significant results in a limited time.

Computer-based simulation
Two CAD software tools were used in this study (Table 1).

Table 1. Main characteristics of the STAR and DYNAMAN CAD software tools

Simulation tool	Specificity	Other characteristics
DYNAMAN software for anthropometric and biomechanical investigations in 0-g environment	Representation of the body kinematics	3D rendering application: – 16-light edition – some choice of colour
	Reproduction of the human visual field	3D animation package
STAR software for architectural design	2D and 3D design	3D visualisation model
	Output diversity: – sections – plans – perspectives	3D rendering application: – 16-colour edition (hue, chroma) – 16-light edition (diffuse, spot)
		3D animation package

DYNAMAN
The DYNAMAN software package was developed in 1988 for ESA (a description of this tool was given in ESA Bulletin No. 67, pages 65-69). DYNAMAN allows the kinematics of mechanical systems, including humanoid models, and the interaction between the various models and their environments, to be simulated and examined on a screen in real time. To facilitate realistic simulation, DYNAMAN includes in its geometrical database three-dimensional graphical models of astronauts of different physical builds. The database includes both 'naked' models of differing heights under 1-g and microgravity conditions, and space-suited models for EVA simulations.

A virtual camera is coupled to each humanoid model's head, allowing the astronaut's field of view to be visualised. To produce the architecture, geometrical models can be imported from other commercial CAD packages, such as CATIA, EUCLID and ESABase.

DYNAMAN is a real-time simulation system (10 frames per second) and therefore the interface with the user is highly interactive. It is possible to activate and control up to six parallel views of the simulation scene, corresponding to six virtual cameras.

STAR Architecture UX
STAR Architecture UX is a commercially-available, CAD software running on a Hewlett-Packard UNIX computer system. It offers a set of specialised applications for the design of architectural projects, the integration of buildings or infrastructures on a site, and the production of plans and written documentation.

With STAR, models are created directly in 3D using simple, parallelepiped (or box-shaped) elements. The 3D elements can then be combined to build complex architectures. The model can be sectioned with planes to obtain views from various typical architectural viewpoints, such as sections, plans, elevations and even axonometry and perspectives. All are calculated automatically by the software, by simply defining the coordinates of a viewing camera and of a target.

The flexibility of the code and the capability of using pre-programmed components and/or groups of elements means that the structural and functional elements can be quickly interchanged, and therefore evaluated faster.

STAR offers a plotting output which permits pre-defined perspective frames to be produced, and gives the user the opportunity to modify the visual angle of the camera in order to simulate the visual field of a virtual human being.

STAR also contains an image-rendering package for visualisation in a 3D mode. It is possible to modify the physical components of colour (hue, value and chroma), the surface reflectivity, the colour intensity and light characteristics (intensity, diffuse or ambient light, cone/parallel spotlight) using 16 different lights. Once the colour, light and shininess of the material have been defined, high-rendering images of the interior arrangements can be produced using colour slides for presentations. STAR can also be combined with other image-rendering applications.

With STAR's animation package, users can 'walk through' the model to verify the validity of the design. The user can 'walk/fly' along a preset path, created by defining a set of positions for a camera and targets, to simulate a translation path and sequence in microgravity, and to investigate the probable visual field of the astronaut inside the module.

For this study, some typical translation paths inside the module were recorded on videotape. The motion sequences recorded included the translation along the main longitudinal axis, the approach to some visually-identifiable equipment such as the ergometer or the wardroom table, and the simulation of the visual field from a number of fixed points.

Reduced-scale mock-up

Another simulation activity is the construction of a model of the proposed module but on a smaller scale. This technique also supports the CAD-based activities. Although it is generally somewhat less flexible than CAD tools, a reduced-scale model offers:

- a three-dimensional presentation of an architectural project
- a relatively high degree of realism
- a relatively high flexibility in comparison with a full-scale mock-up.

Such a mock-up of the overall configuration allows the user to have a general, three-dimensional view of the architectural elements and to evaluate aspects such as the flexibility of the structure, the degree of spaciousness, the astronaut's visual field and module orientation, and, in addition, to test element-related issues such as colour definition, the lighting system, and surface textures and patterns.

In this study, a reduced-scale model of each of the HOUSE, HABEMSI and ENSAD configurations was built on a one-fifth scale. Each model consisted of a cylinder with a height of approximately 2 m and a diameter of approximately 1 m (Fig. 5). It could be disassembled and reconfigured relatively easily to simulate different layouts of cylindrical modules. Its external structure was made of an aluminium frame and shells, which could be mounted in various positions to study different locations of viewing windows, or removed altogether to view the module's interior.

Figure 5. The mock-up — a researcher produces a motion sequence by moving a fibroscope through the mock-up

The internal configuration of the mock-up included decks, walls, racks, stand-off/utility runs, and a wardroom table, which were of customised shape (for each different project). Other items, such as exercise and medical facilities (bike, treadmill, and medical patient restraint table), shower and toilets, were roughly similar for the three architectural configurations. These items were manufactured mostly in plastic.

The reduced-scale mock-up was used:

- to reproduce the visual feeling of a real-size habitat
- to visualise and manipulate directly and easily various items of the architecture, because of the flexibility and reconfigurability of the structure
- to 'enter the module' through the use of a fibrescope (a flexible endoscope)

providing direct views and local illumination
— to give the feeling of moving inside the module, or at least to simulate an astronaut's view from a sequence of pre-selected locations inside the module.

The following video tools were used as a means of approaching real-size feeling when moving inside the model:
— a fibrescope, which provides direct vision through a bundle of fibre optics. The viewing head can be moved by remote control in azimuth and elevation. Several optical adaptors can be connected to the fibrescope head, allowing several viewing angles (40°, 60° or 80°).
— an integrated portable TV unit, combining a monitor and a Video 8 VTR with a compact colour TV camera and control unit. The camera is coupled to the fibrescope eyepiece via an adaptor.

Table 2. Phases of the evaluation process

	Objectives	Investigated parameters	Evaluation supports
Phase 1	Verification of simulation tool consistency	Simulation tool (e.g. realism) Architecture (e.g. orientation) Motion sequence techniques	HOUSE DYNAMAN Mock-up 'Crew Daily Life' sequence
Phase 2	Simulation tool suitability Simulation tool effectiveness Module configuration trade-off	Architectural (e.g. functional, operational, psychological/cognitive) Simulation tool (e.g. realism, detail, colour rendering) Aesthetics, functionality and comfort	HABEMSI ENSAD STAR Mock-up 'Module Visit' sequence

Evaluation methodology

The evaluation was performed in two main phases (Table 2):

— Phase 1: Different simulation tools can present the same object in different ways. Phase 1 focussed on assessing the consistency of the simulation methods used, i.e. whether the CAD-based method and the mock-up gave similar results. It was based on only one configuration of habitation module, the HOUSE configuration.
— Phase 2: This main phase of the study concentrated on evaluating whether the simulation methods used are effective with respect to the evaluation objectives, i.e. different tools may be more effective in showing one parameter such as the visual field within the module. In this phase, the DYNAMAN CAD tool was replaced by the STAR tool. Two of the three architectural projects selected, the HABEMSI and ENSAD configurations, were used.

Two groups of subjects participated in the evaluation (14 in Phase 1 and 23 in Phase 2). They were shown a videotape that presented the architectural projects and then they had to judge several aspects of the architecture, simulation tools and video tool techniques. The data was collected through subjective evaluations, which included questionnaires, comments from subjects and interviews.

Results of the evaluation of the module architectures

Remarks made by the subjects during Phase 1 suggest that the HOUSE project has a number of drawbacks from an ergonomic and psychological point of view. The most frequently quoted problems were the interference created between areas that are adjacent but are for different and mutually incompatible purposes, such as the crew quarters and the wardroom; difficulties in moving between decks; and the lack of visual references. Most subjects also considered the inconsistency of orientation rules to be a negative aspect (the HOUSE configuration does not respect the Earth-like mental image of a single orientation).

Both the HABEMSI and ENSAD modules, evaluated in Phase 2, are considered to be sufficiently spacious and bright. Their architecture (which is more complex in ENSAD) gives the feeling of a large visual field. This is expected to counteract the negative effects of long-duration confinement. In addition, the environment is more aesthetically pleasing in ENSAD (with possibly a positive effect on an astronaut's mood), but more functional in HABEMSI (with possibly a positive effect on the crew's efficiency). However, some improvements are required, particularly in the internal layout (layout of equipment and the adjacency level of rooms), the allowance for privacy, the internal decor, and the colour scheme (Table 3).

Results of the evaluation of the simulation tools

When compared with the computer tools, the mock-up seems to be the most effective simulation tool, particularly regarding the degree of realism and the visual-field rendering provided. The statistical analysis performed underlines a significant difference in effectiveness between the mock-up and STAR average scores, confirming the overall superiority of the mock-up.

Analysis of the results showed that the subject's feeling of reality was related to the quality of the architectural details (for example, the details of the equipment and the ability to distinguish textures) and to the feeling of 'actual-size' (because of the level of detail used, 57% of subjects, who had only seen the mock-up in the video sequence, thought that the mock-up was significantly larger than it actually was). In addition, it was remarked that some of the subjects who were already familiar with 2D drawings of the presented projects, had not noticed a number of features they came across with a 3D presentation, such as the interference of volumes.

The convergence of results from both Phase 1 and Phase 2 appears to confirm the superiority of the mock-up, at least based on the degree of realism and rendering of the visual field, as mentioned earlier. Otherwise, on the basis of light, colour and detail rendering, the mock-up and STAR are similar, and moderately effective. A correlation analysis was also carried out, in order to identify the most suitable simulation tool to use with respect to the specific architectural aspects to be evaluated. This analysis showed that it is desirable to use:

- the mock-up, to evaluate such aspects as the spaciousness of the module, the complexity of the architectural design, the visual field within the module, and the brightness and colour hue
- STAR, to evaluate the complexity of the architectural design (the results were comparable to those from the mock-up), and the shapes used in the decor.

Recommended improvements

It was found that it would be possible, and desirable, to optimise the performance of the simulation tools, particularly that of STAR.

Analysis has demonstrated that the mock-up and STAR are reliable enough to be considered as important simulation tools, but only under given conditions. Some improvements concerning the simulation tools and the investigation support (e.g. motion sequences) are required. For example, comparative analysis showed that subjects were often unable to recognise the STAR configuration when they were shown the videotaped motion sequences. The problems that were reported mostly related to the viewing angle (the camera being too close to the target), the movements of the camera (abrupt variations in the viewing angle), and the speed of the motion sequences (the camera's viewing-angle was changing too quickly), in that order. Indeed, STAR is not meant to be a real-time simulation software package.

The modifications required to improve the effectiveness of the tools do not require excessive effort.

The recommended improvements to the simulation tools are:

- to integrate a proper lighting system in the mock-up
- to use presentation means other than videotape, for instance, still pictures or slides (particularly for STAR)
- to implement more details in the module design (particularly for STAR).

The recommended improvements to the presentation means are:

- to determine the choice of presentation means (motion sequences, slides or pictures) according to the specific objectives of the investigation (global versus detail, static or dynamic)
- to use proper real-time simulation tools to create motion sequences
- to define the contents of the motion sequence according to the specific objectives of the investigation
- to improve the video recording system, in particular the image quality.

Table 3. Features of HABEMSI and ENSAD configurations (as reported by test subjects)

Evaluation criterion	HABEMSI	ENSAD
Aesthetics	Unpleasant environment Cold environment Poor internal design decor	Open space Warm environment Futuristic and unusual architecture
Functionality	'Natural' layout Useful layout Privacy respected	Not functional Inefficient layout of decks Lack of privacy
Habitability	Well-adapted to living and working in for a long period	Well-adapted to living and working in for a short period

Although the effectiveness and the reliability of the DYNAMAN tool were not tested in direct comparison with the mock-up and STAR, DYNAMAN is expected to provide a better understanding of the architectural design, particularly when the design is complex as in ENSAD or HOUSE. Alternating between general and partial views of the module had a 'teaching' effect on the subjects and allowed them to locate the different areas of the habitation module. Also, DYNAMAN would provide a more effective cognitive representation of the internal layout: the presence of a 'human-scale' reference (the humanoid model) helps subjects in orienting themselves within the module.

The evaluation procedure (with an evaluation based on a motion sequence followed by the completion of a questionnaire) might be improved using an interactive, real-time simulation tool like a head-mounted display and a data glove. Subjects could visit the module interactively at their own pace and evaluate its configuration by themselves, without requiring the production of pre-recorded motion sequences. Real-time virtual-reality software simulation tools could offer the required performance.

Future studies should use such tools, in conjunction with STAR and the mock-up, to investigate the dynamic aspects of architecture, i.e. the viewer's motion within the architecture.

Conclusion

The study results have provided guidelines for the future practical use of the simulation tools.

The STAR computer simulation tool should be used:

- to implement and design the architectural project from a technical point of view
- to describe the module configuration
- to investigate aesthetic aspects of the architecture, using slides as a presentation aid.

Real-time virtual-reality software should be used:

- to investigate dynamic aspects of architecture (e.g. translation paths and collision detection), global impressions of the architecture (quality of the environment), ergonomic aspects, and cognitive aspects (orientation, mental representation of the design)
- to conduct dynamic investigations, using a real-time animation package.

A mock-up should be used:

- to implement the module architecture, defined with the use of STAR, under conditions closer to physical reality
- to act as a presentation means using either the actual mock-up, or a videotaped motion sequence, or slide presentations.

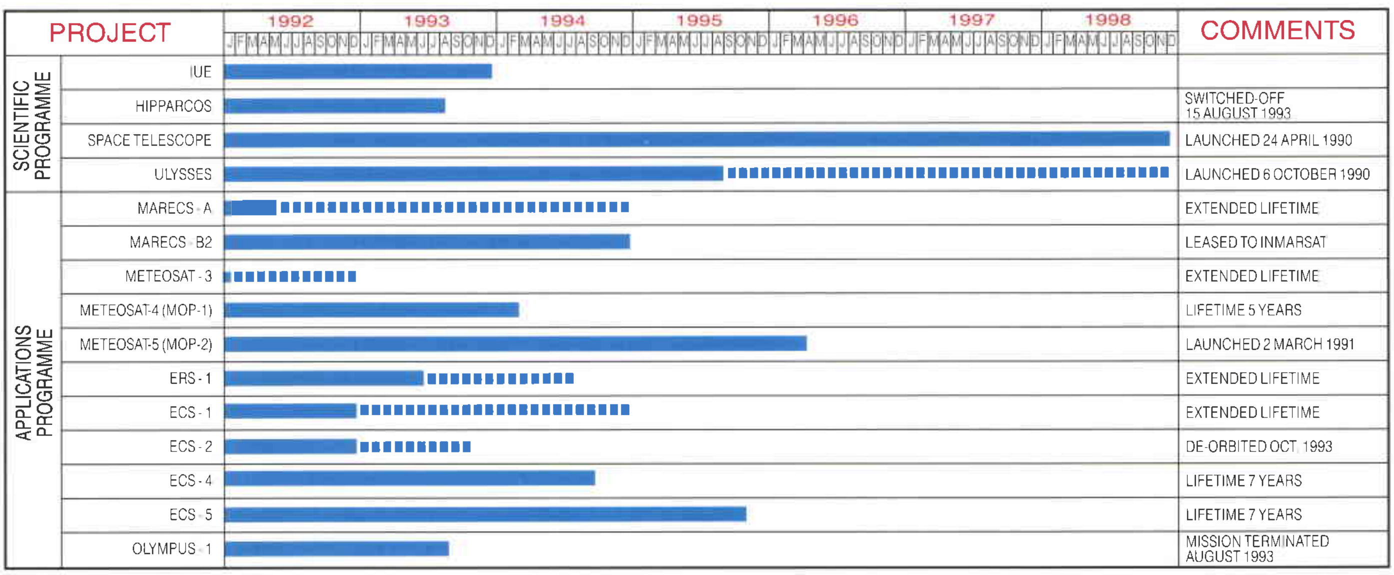
Thus, the diversity of simulation tools and presentation means would cover almost all aspects of the architectural evaluation, both static and dynamic, and that in the context of a 'laboratory', rather than having to use a full-scale construction.

Acknowledgements

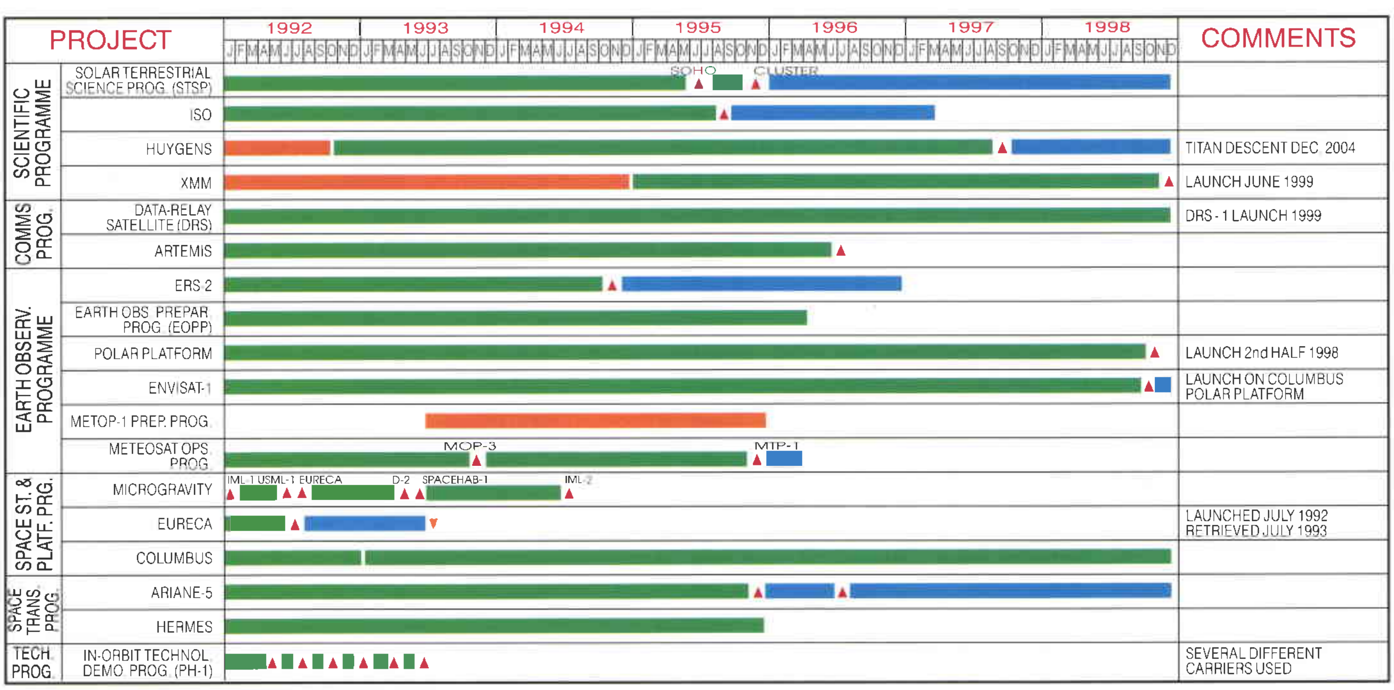
The work reported in this article was performed by ESA Young Graduate Trainees and in-house contractors with the Life Support and Habitability Section of ESTEC (E. Raffner, K. Vergé-Dépré, and D. Antonelli). The author also wishes to acknowledge the valuable contributions from staff and contractors of the Simulation Facilities Section, the Analysis and Verification Section and the Engineering Section of ESTEC, and the Long-Term Programme Office (LTPO) of ESA's Directorate of Space Station and Microgravity.

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

In Orbit / En orbite



Under Development / En cours de réalisation



DEFINITION PHASE
OPERATIONS
MAIN DEVELOPMENT PHASE
ADDITIONAL LIFE POSSIBLE
▲ LAUNCH/READY FOR LAUNCH
▼ RETRIEVAL

Ulysse

La mission se poursuit de manière satisfaisante et il apparaît clairement, au vu des données scientifiques, que la sonde a pénétré dans une région de l'espace qui n'est plus sous l'influence de la zone équatoriale du Soleil. Ce n'est pas une surprise puisque Ulysse aura atteint une latitude solaire de 48° sud à la fin de 1993. Au cours des trois derniers mois, la couverture des données a subi de légères altérations par suite d'un problème matériel à la station du réseau de l'espace lointain de Madrid, l'antenne de 34 m ayant été rendue indisponible par la défaillance d'un support. Toutefois, le taux de couverture a été généralement supérieur à 90% grâce aux solutions de rechange mises en oeuvre par l'équipe Ulysse au Jet Propulsion Laboratory, Pasadena (Etats-Unis).

Le 9 août, la sonde est passée d'elle-même en mode 'sécurité' par la mise hors tension des éléments non essentiels de la charge utile. C'est la troisième fois au cours de la mission qu'une anomalie de ce type se produit, les deux premières ayant eu lieu en juin 1991 et février dernier. Comme précédemment, le logiciel embarqué a coupé l'alimentation des instruments scientifiques et modifié la configuration des sous-systèmes de la sonde, ce qui s'est traduit par une perte temporaire des données de télémesure. Le 13 août, la sonde et sa charge utile ont été remises en configuration nominale.

Les recherches se poursuivent pour détecter l'origine de ces anomalies, qui se sont toutes produites au moment d'une manoeuvre de routine de pointage vers la Terre.

Cluster

Le modèle d'identification du satellite a subi avec succès son programme d'essais électriques, y compris les essais partiels de compatibilité électromagnétique de la charge utile scientifique. La mise à jour du logiciel de la séquence d'essais pour les modèles de vol a commencé.

L'intégration du premier modèle de vol est pratiquement achevée, y compris la charge utile scientifique. Les essais électriques de l'ensemble du système auront lieu en novembre et seront suivis par un transfert à l'IABG à Munich (D) pour le programme d'essais d'ambiance au niveau système. L'intégration des sous-systèmes du second modèle de vol est en cours, celle de la charge utile étant prévue en novembre. La livraison des expériences est en cours afin que cette date puisse être respectée.

La revue de l'ensemble de la mission qui a été conduite récemment a montré que la réalisation de tous les éléments (satellite, charge utile, secteur sol) reste dans les temps pour un lancement fin 1995 bien que la marge du calendrier ait été réduite par suite de retards dans la fourniture de certains equipements.

Il est prévu que le système des données scientifiques de Cluster, conçu pour le traitement de ces données après le lancement, entre dans sa phase de mise en oeuvre début 1994. Ce système s'appuie sur des centres de données répartis dans différents pays d'Europe, aux Etats-Unis, en Hongrie et en Chine. Les données brutes seront diffusées sur CD-ROM à partir de l'ESOC et, une fois traitées, seront mises à la disposition de la communauté des utilisateurs de Cluster à partir des différents centres de données.

Le modèle de vol de la mémoire de masse de Mars 94 a été livré à l'IKI à Moscou, qui a prononcé sa recette. Il est maintenant prêt à être intégré sur le satellite.

Soho

Industrie

Le modèle structurel de l'ensemble du véhicule spatial et de sa charge utile a subi avec succès les essais vibratoires chez Intespace (Toulouse) fin juin. Un essai acoustique a été exécuté selon des niveaux correspondants à une qualification Atlas II AS. A cet effet, le véhicule spatial a été placé dans une 'tente' spéciale en matière plastique afin de vérifier les conditions de propreté offertes par ce type de protection dont l'utilisation est envisagée lors de la campagne relative au modèle de vol . On a ensuite procédé à des essais de vibrations sinusoïdales à partir de l'analyse des charges couplées du véhicule spatial et du lanceur conduite par la NASA. A l'issue de ces essais, les masses fictives et les unités du modèle structurel du véhicule spatial ont été démontées et ses deux demi-structures ont été préparées, comme il était prévu, pour la mise à niveau du modèle d'identification.

Le modèle d'identification du module charge utile (PLM) a été entièrement équipé de ses expériences et unités et les activités d'essais électriques et fonctionnels ont culminé avec l'essai fonctionnel du système à la mi-juillet, au cours duquel toutes les expériences et leurs unités de soutien ont été testées ensemble pour la première fois au cours d'une séquence intégrée présentant une simulation réaliste.

A l'issue de ces essais, les unités et câblages du modèle d'identification ont été entièrement transférées, comme il était prévu, sur le modèle structurel et préparées pour l'exécution des essais fonctionnels au niveau système du modèle d'identification complet.

Le modèle d'identification du module de servitude (SVM) a reçu le dernier sous-système (AOCS) et les unités restantes (batteries, etc.). Chaque sous-système a été intégré et essayé séparément afin de confirmer les essais exécutés par les sous-traitants au niveau sous-systèmes et de préparer les essais système d'ensemble, prévu en septembre.

L'approvisionnement du matériel du modèle de vol s'est poursuivi avec la fourniture de plusieurs unités aux équipes d'intégration des sous-systèmes. Certains problèmes sont apparus pour le calendrier des livraisons du sous-système d'alimentation et l'unité de distribution électrique fait l'objet d'une attention particulière.

La revue critique de conception du véhicule spatial a débuté le 26 juillet avec la livraison du dossier de données par Matra-Marconi Space (France). Il s'agit de l'une des trois revues (les autres étant consacrées à la charge utile et aux opérations sol) qui constituent la revue critique de conception de la mission, dont la commission doit se réunir à la fin du mois d'octobre.

Ulysses

The mission continues to go well, with clear indications in the scientific data that the spacecraft has entered a region of space that is no longer dominated by the Sun's equatorial zone. This is not surprising, as Ulysses will have reached a solar latitude of 48°S by the end of 1993.

In the last three months, the data coverage has suffered slightly as a result of a hardware problem at the Madrid Deep-Space Network station, where the 34 m antenna has been unavailable because of a failed bearing. Nevertheless, coverage has been generally in excess of 90% thanks to workaround solutions implemented by the spacecraft team at Jet Propulsion Laboratory in Pasadena (USA).

On 9 August, the spacecraft entered its 'safe' mode autonomously by disconnecting non-essential loads on the power supply. This was the third time during the mission that this anomaly has occurred, the previous occasions being in June 1991 and February of this year. As in the past, the on-board logic switched off the scientific instruments and reconfigured the spacecraft subsystems, resulting in a temporary loss of telemetry. By 13 August, the spacecraft and its payload had been returned to their nominal configuration.

Investigations into the cause of these anomalies, all of which occurred at the time of a routine Earth-pointing manoeuvre, are continuing.

Cluster

The engineering-model spacecraft has successfully completed its electrical test programme, including partial electromagnetic-compatibility testing of the scientific payload. Updating of the test-sequence software for the flight models has commenced.

The first-flight-model integration is almost complete, including the scientific payload. Full system electrical testing will take place in November, followed by transport to IABG in Munich (D) for the system-level environmental test programme. The second-flight-model subsystem integration is underway, with payload integration planned for November. Experiment deliveries are in progress to meet this date.

The recent end-to-end mission review has shown that all elements – spacecraft, payload and ground segment – are still on schedule for a late-1995 launch, although the schedule margin has been reduced due to late equipment deliveries.

The Cluster Science Data System, designed for post-launch processing of the scientific data, is expected to enter its implementation phase early in 1994. The system relies on distributed data centres in various European countries, the USA, Hungary and China. Raw data will be distributed from ESOC on CD-ROM, and processed data will be made available to the Cluster community from individual data centres.

The Mars 94 mass-memory flight model has been delivered and accepted by IKI in Moscow, and is ready for integration on the spacecraft.

Soho

Industry

The overall spacecraft and payload structural models have successfully undergone vibration testing at Intespace (Toulouse) at the end of June. An acoustic test has been performed at Atlas II AS qualification levels with a special 'tent' of plastic material around the spacecraft, to test this type of cleanliness protection for use in the flight-model campaign. Sine vibration testing followed, based on the coupled load analysis of the spacecraft and the launcher performed by NASA.

After these tests, the structural-model mass dummies and units were dismounted, and the two halves of the structural-model spacecraft structure were readied, as planned, for the engineering-model upgrade.

The engineering model of the Payload Module (PLM) was completely fitted with the engineering model experiments and units, and the electrical and functional test activities culminated in the System Functional Test in mid-July, when experiments and their support units were all tested together for the first time in a realistic integrated sequence.

After the test, all engineering-model units and harnesses were transferred as planned to the structural model and readied for overall engineering-model system functional testing.

The engineering model of the Service Module (SVM) received the last subsystem (AOCS) and other remaining units (e.g. batteries). Each subsystem was integrated and tested separately, to confirm the tests performed by subcontractors at subsystem level and to prepare for the overall system test.

The procurement of the flight-model hardware has progressed, with deliveries of several units to subsystem integration teams. Some problems have been encountered with the power-subsystem deliveries, and the Power Distribution Unit is receiving particular attention.

The Spacecraft Critical Design Review started on 26 July 1993 with the delivery of the Data Package by Matra Marconi Space France (MMS-F). This review is one of three (Payload and Ground Operations being the other two) that constitute the Mission Critical Design Review, the Board for which is planned to meet at the end of October.

ESA-NASA cooperation

The high-power amplifiers and the fine-pointing sun sensor flight models have been delivered and are being used by the relevant subsystem contractors (Alcatel Espace and British Aerospace, respectively).

The second engineering model of the tape recorder has been delivered to Soho after an extensive series of tests, and is being used in the engineering-model tests at Matra Marconi Space (F). Further tests have been performed in July and August on the flight-model tape recorder to be delivered for Cluster, nominally in September, with mixed results, and the persisting technical and late-delivery problems have been receiving the highest attention at NASA and at ESA management level.

General Dynamics has successfully resumed launches of the Atlas vehicles, after the causes of the failure of flight AC-74 in March 1993 were identified and corrected. Preparations for the Soho launch in July 1995 are proceeding on schedule.

Coopération entre l'ESA et la NASA

Les modèles de vol des amplificateurs haute puissance et des détecteurs à référence solaire et pointage fin ont été livrés et sont actuellement utilisés par les contractants respectifs des sous-systèmes (Alcatel Espace et British Aerospace).

Le deuxième modèle d'identification de l'enregistreur à bande a été livré à Soho et, après une série d'essais poussés, est actuellement utilisé dans les essais du modèle d'identification qui ont lieu chez Matra Marconi Space. D'autres essais ont été conduits en juillet et août sur le modèle de vol de l'enregistreur à bande, qui devait normalement être livré en septembre pour Cluster. Les résultats mitigés obtenus à cette occasion et la persistance de problèmes techniques et de retards de livraison sont examinés avec le plus grand soin par les responsables de la NASA et de l'ESA.

General Dynamics a repris avec succès le lancement de ses véhicules Atlas après avoir détecté l'origine de l'échec du vol AC 74 en mars 1993 et pris les mesures correctives adéquates. Les préparatifs du vol de Soho en juillet 1995 se poursuivent conformément au calendrier.

La revue de conception du secteur sol au niveau système a eu lieu fin juillet au Centre spatial Goddard de la NASA avec la participation de l'ESA. Elle a confirmé l'avancement des activités relatives au secteur sol et a mis en lumière certaines améliorations à apporter dans les échanges d'informations entre les deux agences.

Expériences

Au cours de la réunion du Groupe de travail scientifique qui s'est tenue début juillet, l'équipe du projet et les responsables de recherche ont fait le point sur les fournitures des modèles de vol d'expériences qui doivent avoir lieu entre octobre 1993 et janvier 1994. Pratiquement toutes les équipes ont procédé aux essais de leurs capteurs et de leurs unités et certains points critiques qui sont apparus en matière de calendrier ont été suivis de près.

Les problèmes techniques et de calendrier qui se posent pour les détecteurs que la NASA doit fournir pour deux instruments principaux (SUMER et UVCS) ont été étudiés avec une attention particulière par l'ESA et la NASA au plus haut niveau de leurs directions respectives.

ISO

Instruments scientifiques

Les unités du plan focal des instruments scientifiques sont en cours d'installation sur le modèle de vol du télescope, qui doit être intégré dans le module charge utile. On a procédé à l'intégration et aux essais de toutes les unités électroniques de l'instrument scientifique sur la plate-forme supérieure du module de servitude.

ISO flight-model liquid-helium cryostat on service module structure during vibration testing at IABG (Munich) (Photo courtesy of DASA)

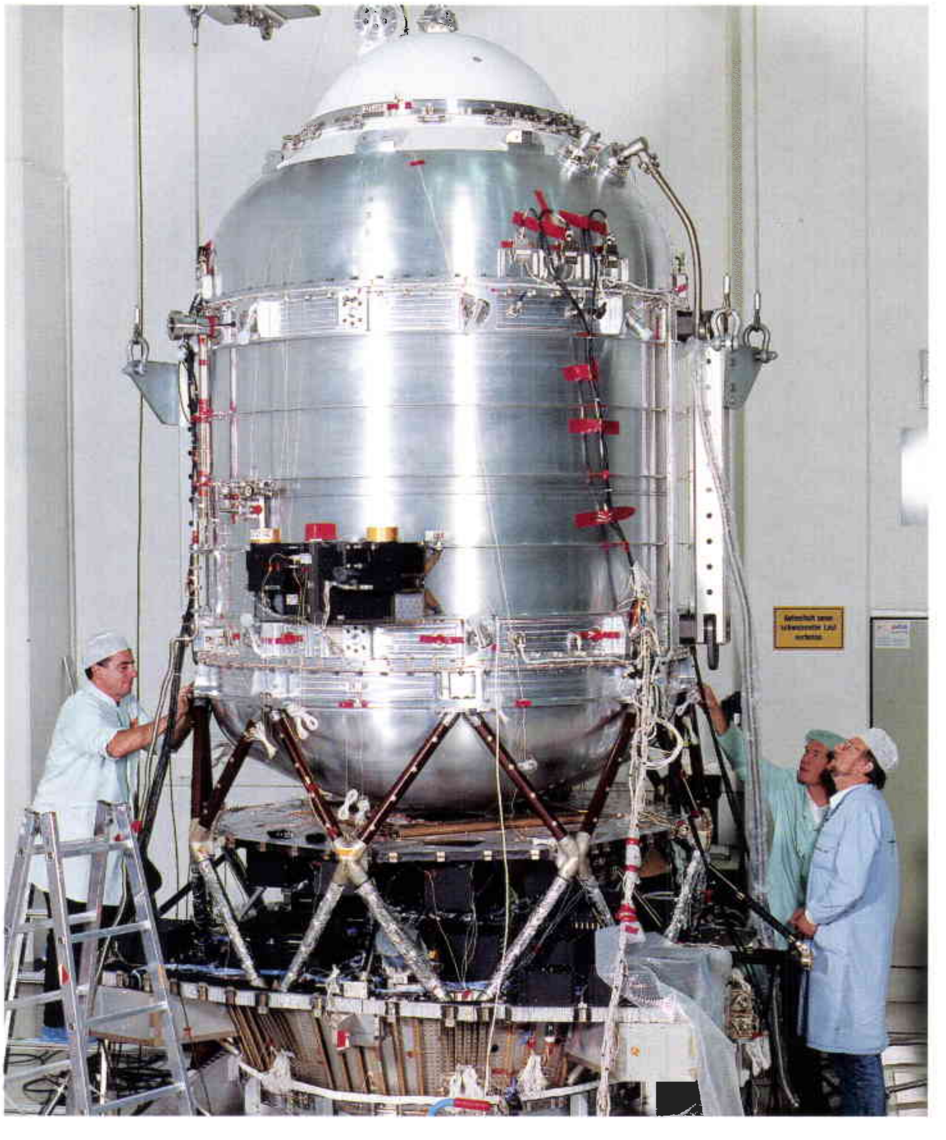
Essais aux vibrations du cryostat à l'hélium liquide du modèle de vol d'ISO sur la structure du module de service chez IABG à Munich (photo DASA)

Les groupes de responsables de recherche escomptent que toutes les unités de rechange seront prêtes à être livrées vers la fin de l'année.

Satellite

Les activités relatives au matériel du modèle de vol du satellite progressent de manière satisfaisante. Le module charge utile a passé avec succès ses essais cryogéniques et vibratoires. Une étape importante pour le projet a été franchie avec l'exécution réussie des essais de qualification et de recette des vannes à hélium liquide, qui ont maintenant été installées dans le module charge utile. On procèdera ensuite à l'installation du télescope et des instruments scientifiques, avant de refermer le module charge utile pour la suite des essais.

L'intégration et les essais du module de servitude sont pratiquement achevés. Celui-ci sera livré à l'ESTEC en octobre pour des essais de propreté



The Ground Segment System Design Review took place at the end of July at NASA Goddard Space Flight Center with ESA participation. It confirmed the progress of the ground-segment activities and highlighted improvements to be introduced in the exchange of information between the two Agencies.

Experiments

During the Science Working Team Meeting at the beginning of July, the Project Team and the Principal Investigators discussed the deliveries of the flight models of the experiments that will take place between October 1993 and January 1994. Almost all teams have been testing their sensors and units, and some reported schedule criticality has been closely monitored.

The technical and schedule problems with the NASA-supplied detectors for two major instruments (SUMER and UVCS) have received specific attention at ESA and NASA senior-management level.

ISO

Scientific instruments

The focal-plane units of the scientific instruments are now installed on the flight-model telescope, which is to be integrated into the payload module. All electronic units of the scientific instruments have been integrated and tested on the service-module upper platform.

The Principal Investigator groups are expecting to have all spare units ready for delivery around the end of the year.

Satellite

Good progress is being made with the satellite flight-model hardware. The payload module has successfully passed its cryogenic and vibration tests. A major project hurdle was overcome with the successful completion of qualification and acceptance testing of the liquid-helium valves. These valves have now been installed in the payload module. The telescope with scientific instruments will be installed next, before closing the payload module for further testing.

The service module's integration and testing is nearly complete. It will be delivered to ESTEC in October for electromagnetic-cleanliness tests and for testing with the flight-operations software developed by ESOC. Special actions are being taken to improve the pointing performance of the star tracker to within its specification.

The satellite work is on schedule for the September 1995 target launch date.

Ground segment

Spacecraft flight operations are proceeding satisfactorily. The science operations team is being strengthened to resolve the problems of the very complex science operations software development.

Further progress has been made in agreeing the details whereby NASA could provide the second ground station for ISO. Draft Memoranda of Understanding are being exchanged with NASA and Japan concerning the potential cooperation on ISO.

Huygens

A great deal of effort and attention during the past three months has been devoted to the finalisation of contractual agreements with industry for the development and supply of Probe constituents and supporting equipment. The extent of agreements on technical baseline documents has increased significantly which, together with the completion of negotiations on Probe subsystem prices, provides a sound contractual basis for the overall Probe development programme, due to be formalised by signature of the prime contract in September.

Design and development activities in industry have generally progressed in line with expectations and hardware – Huygens Probe interface simulators – has already been delivered to experiment groups. Problems are being experienced, however, in relation to high-reliability parts and a deployment device. The situation is being closely monitored, with corrective measures ready for implementation.

Management and interface working meetings have been held with NASA/Jet Propulsion Laboratory and experimenter groups. At the request of the Cassini Orbiter spacecraft magnetometer Experimenter, a Huygens-dedicated Magnetics Workshop was held at ESTEC. The conclusions of the Workshop were deemed satisfactory to all parties.

ERS

ERS-1

The satellite's performance has remained extremely stable over the reporting period, with a platform availability of 100%, and instrument operations above 98%. The cumulative instrument availability since launch amounts to 96% for the Active Microwave Instrument (AMI), 96% for the Radar Altimeter (RA), and 97% for the Along-Track Scanning Radiometer (ATSR), including unavailabilities induced by the platform and the on-board data recording/transmission subsystems. Analysis of instrument performances over the first two years of the mission shows extremely good correlation between early commissioning results and current performances.

The satellite's orbit has continued to be maintained within its ±1 km deadband, and the current 35 day orbit repeat cycle will be maintained until 20 December 1993.

The Low Bit Rate (LBR) global data mission has continued to be performed nominally, together with its associated Fast Delivery service and off-line archiving and processing.

Several meteorological entities, in particular the UK Meteorological Office and the European Centre for Medium-Range Weather Forecasts, have continued assimilating the improved wind and wave Fast Delivery products into their models, with continued very encouraging evaluation results.

SAR data acquisition by the network of ESA, National and Foreign Stations has continued, as has the associated data processing and Fast Delivery service at the ESA stations. Acquisition campaigns over Antarctica have been supported successfully by the German O'Higgins station (12 Aug.–12 Sept.) and the Japanese Syowa station (42 orbits acquired in August).

During the reference period, test campaigns have been successfully *electromagnétique et pour expérimenter le logiciel d'exploitation en vol mis au point par l'ESOC. Des mesures spécifiques sont en cours pour mettre les caractéristiques de pointage du suiveur d'étoiles en conformité avec ses spécifications.*

Les travaux sur le satellite sont dans les temps pour un lancement prévu en septembre 1995.

Secteur sol

Les activités liées à l'exploitation en vol du satellite se déroulent de manière satisfaisante. L'équipe chargée des opérations scientifiques est actuellement renforcée pour résoudre les problèmes que pose la réalisation très complexe du logiciel qui s'y rapporte.

De nouveaux progrès ont été faits sur la voie d'un accord relatif aux modalités précises selon lesquelles la NASA pourrait fournir la deuxième station sol d'ISO. Des projets de mémorandums d'accord sont étudiés avec la NASA et le Japon en ce qui concerne les possibilités de coopération pour ISO.

Huygens

Au cours des trois derniers mois, d'importants efforts ont été consacrés à la mise au point finale d'accords contractuels avec l'industrie pour la réalisation et l'approvisionnement des éléments constitutifs de la sonde et de ses équipements de soutien. Les points d'accord sur les documents de référence technique progressent de manière significative, offrant ainsi, avec l'achèvement des négociations relatives aux prix des sous-systèmes de la sonde, une bonne base contractuelle pour l'ensemble du programme de développement, qui doit être officialisé par la signature du contrat de maîtrise d'oeuvre en septembre.

D'une manière générale, les activités de conception et de réalisation dans l'industrie ont avancé conformément aux prévisions et les groupes d'expérimentateurs ont déjà reçu du matériel sous forme de simulateurs d'interface de la sonde Huygens. Des problèmes sont toutefois apparus en ce qui concerne certains composants à haute fiabilité, ainsi qu'un dispositif de déploiement. La situation est suivie de près, certaines mesures correctives étant prêtes à être mises en oeuvre.

Des réunions de travail consacrées à la gestion et aux interfaces ont été organisées avec le Jet Propulsion Laboratory de la NASA et avec les groupes d'expérimentateurs. A la demande de l'expérimentateur travaillant sur le magnétomètre de l'orbiteur Cassini, un atelier sur le magnétisme s'est tenu à l'ESTEC pour Huygens. Les conclusions de cet atelier ont été satisfaisantes pour toutes les parties.

ERS

ERS-1

Le fonctionnement du satellite est resté extrêmement stable depuis le dernier rapport, avec un taux de disponibilité de 100% pour la plate-forme et de plus de 98% pour les instruments. La disponibilité totale des instruments depuis le lancement s'établit à 96% pour le détecteur actif à hyperfréquence (AMI), 96% pour l'altimètre radar (RA) et 97% pour le radiomètre à balayage le long de la trace (ATSR), compte tenu des temps de non-disponibilité dus à la plate-forme et aux sous-systèmes embarqués d'enregistrement et de transmission des données. L'analyse des caractéristiques de fonctionnement des instruments sur les deux premières années de la mission fait apparaître une corrélation extrêmement bonne entre les premiers résultats de la phase de recette et les performances actuelles.

L'orbite du satellite a été maintenue à l'intérieur de sa bande de ±1 km, et le cycle orbital de 35 jours sera conservé jusqu'au 20 décembre 1993.

La mission de recueil de données à faible débit (LBR) à l'échelle du globe s'est poursuivie de façon nominale, ainsi que le service de livraison rapide et les activités de traitement et d'archivage correspondantes.

Plusieurs services météorologiques, notamment la météorologie britannique et le Centre européen pour les prévisions météorologiques à moyen terme, ont continué d'incorporer dans leurs modèles les produits vents et vagues améliorés à livraison rapide avec des résultats continus très encourageants en matière d'évaluation.

L'acquisition des données du radar à synthèse d'ouverture (SAR) dans le réseau de stations ESA, nationales et étrangères s'est poursuivie, de même que le service correspondant de traitement des données et de livraison rapide dans les stations ESA. Des campagnes d'acquisition au-dessus de l'Antarctique ont été menées à bien avec le soutien actif de la station O'Higgins de l'Allemagne (12 août-12 septembre) et de la station Syowa du Japon (42 orbites acquises en août).

Pendant la période de référence, Pare Pare (Indonésie), Taiwan et la station allemande transportable ont mené à bien des campagnes d'essai, en vue de l'acquisition des données SAR.

L'élaboration et la distribution nominales de produits standard LBR et de produits en différé se sont également poursuivies. Notamment:

- *Les données FD du RA et du diffusiomètre 'vents' sont désormais diffusées dans un délai inférieur à deux mois.*
- *Les données RA de niveau 2 utilisant l'orbite précise qu'autorise la PAF allemande ont continué à être distribuées aux chercheurs principaux pour le cycle de répétition de 35 jours.*
- *La PAF du Royaume-Uni a confectionné des produits de base 'écho radar' (WDR) à partir de plus de 2900 orbites entre avril 1992 et mars 1993.*
- *Les produits de base 'écho radar' à correction géophysique (WAP), disponibles depuis mai 1993, ont désormais remplacé les WDR. Quelque 1200 orbites de ces produits ont déjà été distribuées.*

Le deuxième symposium ERS-1 organisé pour la présentation des résultats obtenus à ce jour par les chercheurs principaux et les chefs de projets pilotes retenus par l'ESA s'est tenu du 11 au 14 octobre 1993 au Centre des congrès de Hambourg.

Devant la réussite d'ERS-1, la phase d'exploitation a été prolongée d'au moins une année.

ERS-2

Le module charge utile ERS-2 est aujourd'hui tout à fait intégré et l'ensemble des préparatifs a été achevé performed for SAR acquisition with Pare Pare (Indonesia), Taiwan, and the German Transportable Station.

Offline and Low-Bit-Rate (LBR) standard products have also continued to be generated and distributed nominally. In particular:

- Radar Altimeter (RA) and Wind Scatterometer FD data are now distributed within 2 months.
- The RA level-2 data using the precise orbit generated at the German PAF continued to be delivered to PIs for the 35 day repeat cycle.
- The Waveform Foundation Product (WDR), derived from more than 2900 orbits in the period April 1992 to March 1993, has been generated at the UK PAF.
- The geophysical Waveform Products (WAP), which have been available since May 1993, have now superseded the WDR product. Some 1200 orbits of this product have already been distributed.

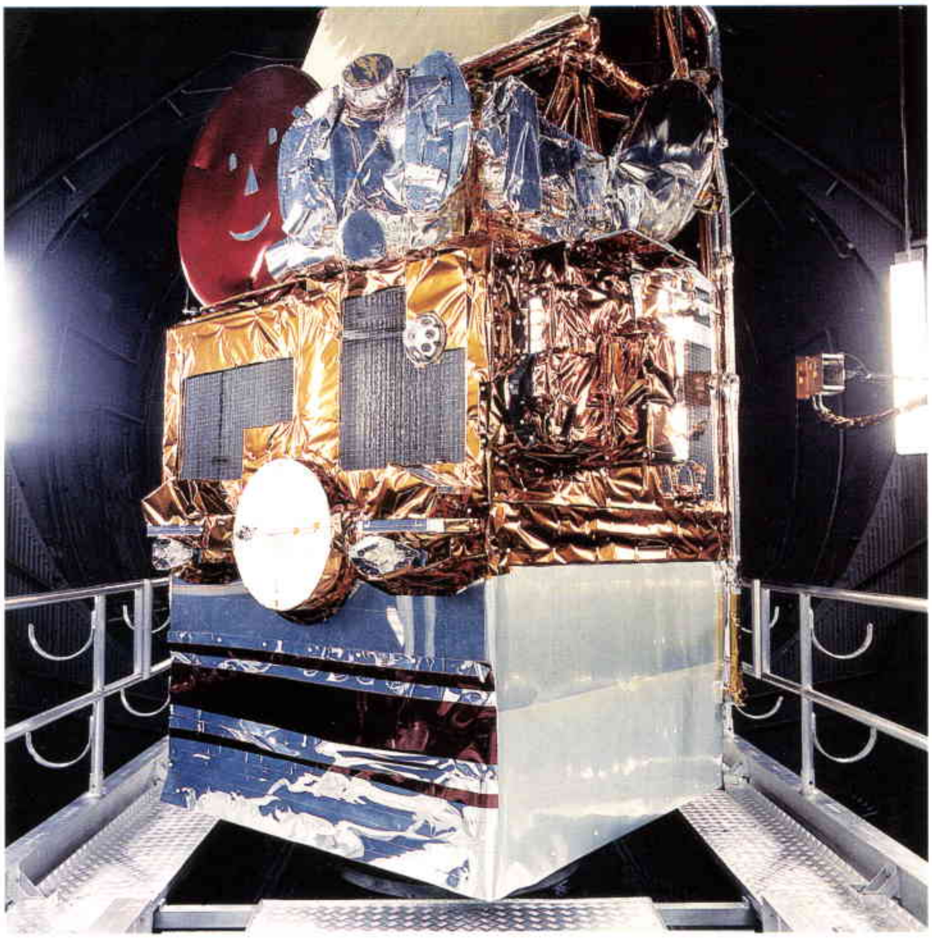
The second ERS-1 Symposium, at which the results obtained to date by the ESA-selected Principal Investigators and Pilot Project Managers will be presented, will be held at the Hamburg Congress Centre on 11–14 October 1993.

As a result of the success of ERS-1, the exploitation phase has been extended for at least a further year.

ERS-2

The ERS-2 Payload Module has now been fully integrated and all preparations completed on schedule so that the thermal-balance/thermal-vacuum tests can start in the Large Space Simulator at ESTEC (NL) in early September. This important milestone in the ERS-2 Programme will demonstrate that the adaptations to the proven ERS-1 design – mainly for the Global Ozone Monitoring Experiment (GOME) – have been correctly implemented with respect to the space environment and, furthermore, will prove the overall integrity of the payload.

Another major milestone for the ERS-2 Programme was reached in June, with the successful GOME Critical Design Review in Florence (I) at Officine Galileo, the instrument's Prime Contractor. GOME, a four-channel nadir sounding spectrometer covering near-ultraviolet and visible wavelengths, is the first European spaceborne instrument for measuring ozone and related trace gases.



ERS-2 under test in the Large Space Simulator (LSS) at ESTEC (NL)

ERS-2 dans le Grand Simulateur spatial de l'ESTEC (Pays-Bas)

Other activities in the ERS-2 Programme continue on schedule: the platform integration activities are nearly complete, with thermal-vacuum testing scheduled later this year in Toulouse (F). Work to prepare the ERS-2 ground segment – which is, to a large extent, the operational ERS-1 ground segment – has been initiated.

An Announcement of Opportunity is now being prepared to provide scientists with the possibility to exploit ERS-2 data, especially with regard to the new or modified instruments (GOME, ATSR-2 and PRARE). The advantages and possibilities associated with parallel operation of both ERS-1 and ERS-2 will be assessed in this process.

EOPP

Solid Earth

Various activities have been initiated in anticipation of approval by the Agency's Earth-Observation Programme Board of the revised Solid-Earth Programme strategy. These activities are related to a possible joint ESA/Russian experiment utilising H-masers. A meeting on this topic at ESTEC on 29–30 June was attended by some 50 scientists and engineers.

Meteosat Second Generation

A joint meeting of the ESA MSG Potential Participants and a Task Force of the Eumetsat Council was held on 16 June to discuss the details of the ESA/Eumetsat Cooperative Agreement. The next Potential Participants meeting is planned for 29 September 1993.

The MSG Phase-B tender documents have been prepared and are ready for issue, subject to approval of the Procurement Proposal by the ESA Industrial Policy Committee. Meanwhile, Phase-A and Phase-A/B bridging activities continue in industry.

dans les délais, de sorte que les essais de bilan thermique et les essais thermiques sous vide pourront démarrer début septembre dans le grand simulateur spatial de l'ESTEC (NL). Cette étape importante du programme ERS-2 doit démontrer que les adaptations apportées à la conception d'ERS-1 – principalement en ce qui concerne l'expérience de surveillance de l'ozone à l'échelle du globe (GOME) – ont été correctement mises en oeuvre en fonction de l'environnement spatial et, de plus, que la charge utile fonctionne normalement dans son intégralité.

Une autre étape importante du programme ERS-2 a été franchie en juin avec le succès de la revue critique de définition du GOME à Florence (I) chez Officine Galileo, contractant principal de l'instrument. GOME, spectromètre à sondage vertical à quatre canaux dans les longueurs d'onde du proche ultraviolet et du visible, est le premier instrument européen embarqué sur satellite devant mesurer l'ozone et les gaz à l'état de traces qui sont en relation avec celui-ci.

Les autres activités du programme ERS-2 se déroulent conformément au calendrier: les activités d'intégration de la plate-forme sont presque achevées, des essais thermiques sous vide devant être menés à Toulouse (F) à la fin de l'année. On a mis en route les travaux de préparation du secteur sol d'ERS-2, qui est, dans une grande mesure, le secteur sol opérationnel d'ERS-1.

Un avis d'offre de participation est en cours de préparation afin de donner aux chercheurs la possibilité d'exploiter les données d'ERS-2, particulièrement pour ce qui concerne les instruments récents ou ayant fait l'objet de modifications (GOME, ATSR-2 et PRARE). Ce sera l'occasion d'évaluer les avantages et les possibilités découlant de l'exploitation parallèle d'ERS-1 et d'ERS-2.

EOPP

Solide terrestre

Anticipant l'approbation du Conseil directeur du programme d'observation de la Terre, l'Exécutif a engagé diverses activités en matière de stratégie révisée pour un programme d'étude du solide terrestre. Ces activités sont liées à une éventuelle expérience commune ESA/Russie utilisant des masers à hydrogène. Une réunion de travail consacrée à cette question s'est tenue à l'ESTEC, les 29 et 30 juin, en présence d'une cinquantaine de scientifiques et d'ingénieurs.

Météosat de deuxième génération

Une réunion commune entre les participants potentiels au programme MSG de l'ESA et le sous-groupe du Conseil d'Eumetsat a eu lieu le 16 juin pour discuter des détails de l'accord de coopération entre l'ESA et Eumetsat. La prochaine réunion des participants potentiels doit se tenir le 29 septembre.

Les documents d'appel d'offres relatifs à la phase B du MSG ont été préparés et sont prêts à être envoyés, sous réserve de l'approbation de la proposition d'approvisionnement par le Comité de la politique industrielle de l'ESA. Pendant ce temps, les activités de phase A et les activités de phase relais A/B se poursuivent dans l'industrie.

Autres missions

L'appel d'offres pour la phase A de Métop-1 a été lancé début juillet.

La définition des études en vue de l'utilisation éventuelle de petits satellites pour l'observation de la Terre est en préparation. Les études scientifiques, techniques et technologiques se sont poursuivies dans le cadre de la préparation des instruments destinés aux futures missions.

Campagnes

La première réunion des expérimentateurs de l'EMAC s'est tenue à Paris les 17 et 18 juin. L'EMAC est une campagne organisée conjointement par l'ESA et par le Centre commun de recherches des Communautés européennes.

Les analyses des campagnes précédentes, telles que Hapex-Sahel et Sarex, se sont poursuivies.

Plate-forme polaire

Afin d'arrêter définitivement la nouvelle conception de la PPF destinée à la mission Envisat-1, une revue de consolidation a été conduite par l'Agence et par l'industrie en juin/juillet. A la suite de cette réunion, un grand nombre de plans et de spécifications du niveau supérieur sont désormais approuvés, et la conception de référence est confirmée.

Les interactions avec les activités d'Envisat-1 ont également été définies dans le détail en vue d'harmoniser les interfaces techniques et de gestion.

Les travaux de développement ont suivi leur cours en parallèle, un certain nombre d'éléments du matériel étant désormais fabriqués (plusieurs équipements MGSE ont été livrés, le modèle structurel du module de servitude est assemblé et prêt à subir les essais statiques de qualification).

Les négociations finales de plusieurs sous-contrats relatifs au module de servitude et au compartiment des équipements de charge utile ont été achevées, l'objectif général étant de passer le contrat de phase C/D avant la fin de 1993.

Envisat-1

Au titre de la Déclaration POEM-1, l'instrument DORIS (détermination Doppler d'orbite et radiopositionnement intégrés par satellite) fait désormais partie de la charge utile d'Envisat-1 à titre d'instrument 'AO' (Avis d'offre de participation).

Du côté industriel, l'Exécutif a reçu fin août une proposition actualisée prenant en compte un certain nombre de modifications récemment apportées au consortium industriel.

Pour les instruments d'Envisat-1, les revues de conception préliminaires sont programmées pour la fin de 1993 et le début de 1994.

POEM-1

Programme préparatoire

Les études de phase B au niveau système et instruments sont aujourd'hui achevées.

Les deux avenants aux études de phase B des instruments ASCAT et MIMR ont

Other missions

The Metop-1 Phase-A Invitation to Tender (ITT) was issued at the beginning of July.

Definition of studies for the possible utilisation of small satellites for Earth observation is in progress. Scientific, technical and technological studies have continued in preparation for future mission instruments.

Campaigns

The first EMAC Experimenters meeting was held in Paris on 17 and 18 June 1993. EMAC is a jointly organised campaign by ESA and Joint Research Centre (JRC) of the European Community.

Analyses of previous campaigns such as Hapex-Sahel and Sarex has continued.

Polar Platform

In order to finalise the reorientation of the PPF design to serve the Envisat-1 mission, a consolidation review by the Agency and industry took place in June/July. As a result, a large number of top-level specifications and plans have now been approved and the design baseline confirmed.

Detailed interactions with the Envisat-1 activities have also taken place in order to harmonise technical and management interfaces.

In parallel, development activities have proceeded, with a number of hardware items now manufactured (several MGSE items delivered, Service Module Structural Model assembled and ready for qualification static tests).

Final negotiations of several subcontracts involving the Service Module and Payload Equipment Bay have been completed with the general objective of placing the Phase-C/D contract before the end of 1993.

Envisat-1 Programme

As part of the POEM-1 Declaration, the Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS) instrument is now included in the Envisat-1 payload complement as an 'Announcement of Opportunity Instrument'.

On the industrial side, an updated proposal was received at the end of August taking into account a number of changes recently introduced in the Industrial Consortium.

Preliminary Design Reviews for the Envisat-1 instruments are planned for the end of 1993 and early 1994.

POEM-1 Preparatory Programme

System and instrument Phase-B studies

These studies have now been completed.

ASCAT and MIMR instrument Phase-B studies

Both riders to the Phase-B studies of these instruments have been successfully completed. The further activities form part of the Metop-1 Preparatory Programme.

Ground segment Phase-B

The final presentation took place in September.

Earthnet

MOS (Marine Observation Satellite) and Spot data have continued to be acquired routinely at Maspalomas.

The Earthnet-Coordinated Tiros Network has also continued to provide a regular data flow from the NOAA-11 (afternoon) and NOAA-12 (morning) missions, with data being acquired at all ground stations, including Scanzano (Italy), which had recently been integrated into the network and which will shortly have a local archiving capability available.

The joint NASA/NOAA/ESA Project '1 km Global Land AVHRR Data Set' has progressed towards Phase-2. A first data-processing prototype has been implemented at the EROS Data Center, following the IGBP algorithm. This has allowed a sample global product to be generated.

The 'IONIA' AVHRR CD-Browser, with over 50 000 products derived from the NOAA AVHRR satellite series data processed in Frascati, has been distributed to the user community.

Within the ASEAN project, the work station delivered to Manila has entered into operation for AVHRR data processing, the training of personnel having been completed at ESRIN.

The upgrading activities to handle the Landsat-6 TM and Panchro payload data are in their final stages. The satellite is scheduled for launch in Autumn 1993.

The JERS-1 SAR and OPS payload data have been recorded according to plan at Fucino (SAR and OPS), Kiruna (OPS), Tromsø (SAR) and O'Higgins, Antarctica (SAR). Activities are in hand at ESRIN to develop an experimental OPS stereo-image prototype. Both the SAR and OPS catalogues have been updated. The OPS digital quick-look is routinely generated. A preliminary data distribution of SAR and OPS test tapes to the Principal Investigators is foreseen in the Autumn. The anticipated distribution agreement between ESA and NASDA is expected to be finalised before the end of the year.

The Level-3 processing of Coastal-Zone Colour Scanner 'OCEAN' products has progressed at JRC/Ispra (I) with product shipment to ESRIN. In parallel, the distribution of Level-1/2 data products to researchers has continued. The 'OCEAN' CD-Browser, containing a considerable amount of ocean-colour data collected by Nimbus-7 over all the main European basins, has also been widely distributed.

Meteosat

The acceptance testing of the MOP-3 spacecraft has been completed at Aerospatiale (F) in preparation for a November launch. All test data were reviewed, as were the spacecraft records, in a series of panel meetings, leading up to the Flight Acceptance Review, held at ESTEC in late August. The successful completion of the review clears the way for the launch campaign, now scheduled to start in the last week of September, culminating in a launch on 19 November.

Meanwhile, a review of the Ground Segment found it ready to support the MOP-3 launch and the commissioning.

été menés à bien. Les activités ultérieures font partie du programme préparatoire Métop-1.

Phase B du secteur sol

La présentation finale a eu lieu en septembre.

Earthnet

L'acquisition régulière des données des satellites MOS (satellite d'observation des mers) et Spot s'est poursuivie à Maspalomas.

Le réseau Tiros coordonné par Earthnet a également continué à fournir un flux régulier de données des missions NOAA-11 (après-midi) et NOAA-12 (matin), captées par toutes les stations sol, y compris celle de Scanzano (I) récemment intégrée au réseau et qui disposera prochainement d'une installation locale d'archivage.

Le projet commun NASA/NOAA/ESA qui vise la production d'un ensemble de données AVHRR sur les terres à l'échelle du globe offrant une résolution de 1 km a progressé vers sa phase 2. Un premier prototype de traitement des données a été mis en oeuvre au Centre de données EROS selon l'algorithme IGBP (Programme international pour l'étude de la géosphère et de la biosphère), ce qui a permis d'élaborer un échantillon de produit à l'échelle du globe.

Les utilisateurs ont reçu le CD 'IONIA' AVHRR qui comporte plus de 50 000 produits élaborés à partir des données de la série des satellites AVHRR de la NOAA, traitées à Frascati.

Dans le cadre du projet ASEAN, le poste de travail livré à Manille est entré en service pour le traitement des données AVHRR, la formation du personnel ayant été achevée à l'ESRIN.

Les activités de mise à niveau nécessaires pour traiter les données des charges utiles TM et Panchro de Landsat-6 sont en phases finales, Le satellite doit être lancé à l'automne 1993.

Les données des charges utiles SAR et OPS de JERS-1 ont été enregistrées comme prévu à Fucino (SAR et OPS), Kiruna (OPS), Tromsø (SAR) et O'Higgins dans l'Antarctique (SAR). On travaille à l'ESRIN sur la mise au point d'un prototype expérimental d'image stéréo OPS. Les catalogues SAR et OPS ont été mis à jour. Des images numériques visualisation rapide d'OPS sont produites systématiquement. Il est prévu de procéder à l'automne à une première distribution des bandes d'essais SAR et OPS aux chercheurs principaux. Le projet d'accord de distribution entre l'ESA et la NASDA doit être définitivement mis au point avant la fin de l'année.

Le traitement de niveau 3 des produits 'OCEAN' de l'analyseur 'couleurs de la mer' pour zones côtières a progressé au Centre commun de recherches d'Ispra (I) et des produits ont été envoyés à l'ESRIN. La distribution de produits de données de niveaux 1-2 aux chercheurs s'est poursuivie en parallèle. Le CD 'OCEAN' qui contient une quantité considérable de données couleur sur les océans, recueillies par Nimbus-7 au-dessus de tous les principaux bassins européens, a également été largement distribué.

Météosat

Les essais de recette du satellite MOP-3 (Programme Météosat opérationnel) se sont achevés à l'Aérospatiale (F) en vue d'un lancement en novembre 1993.

Plusieurs réunions de groupes d'experts ont passé en revue toutes les données des essais ainsi que les dossiers du véhicule spatial, ce qui a conduit à la revue de recette pour le vol qui s'est tenue à l'ESTEC fin août. La bonne exécution de la revue ouvre la voie à la campagne de lancement débutant fin septembre, pour aboutir au lancement le 19 novembre.

Pendant ce temps, le groupe de revue du secteur sol a jugé celui-ci prêt au soutien du lancement et de la recette de MOP-3.

MOP-3 – qui, une fois placé sur son orbite, aura pour nom Météosat-6 – sera mis en réserve en vue de remplacer Météosat-4 en tant que satellite opérationnel, puisque ce dernier a presque épuisé ses ergols et sera expulsé de l'orbite géostationnaire au cours des mois prochains.

L'ESA construit le satellite Météosat MTP pour le compte d'Eumetsat. En juillet, une revue de la base de référence de la production s'est tenue à l'Aérospatiale, contractant principal. Ce satellite sera, pour l'essentiel, identique au satellite MOP, néanmoins il faut s'assurer que les nouveaux composants plus performants n'induisent pas de problèmes d'interface au niveau système. Le groupe de revue a donné son accord pour l'achèvement de la fabrication de tous les sous-systèmes. L'intégration du satellite débutera en 1994 et le lancement est prévu pour 1995/1996.

The O'Higgins ground station in Antarctica

La station terrienne d'O'Higgins en Antarctique

MOP-3 – which will be known as Meteosat-6 once in orbit – will be on standby to replace Meteosat-4 as the operational spacecraft, since the latter is running low on fuel and will be removed from geostationary orbit in the next few months.

The Meteosat MTP spacecraft is being manufactured by ESA on behalf of Eumetsat. A Production Baseline Review was held in July at Aerospatiale, the prime contractor. The spacecraft will be essentially identical to the Meteosat Operational Programme (MOP) spacecraft, but care has to be taken to ensure that new higher-performance components do not lead to interface problems at system level. The Review cleared all subsystems for completion of manufacturing. Integration of the spacecraft will start in 1994, with launch scheduled for 1995/96.

Metop-1 Preparatory Programme

Initial activities have been started to develop ASCAT and MIMR to the level of technology demonstrators in preparation for the Metop-1 Programme. In particular, Requests for Quotation (RFQs) for the development of ASCAT and MIMR technology demonstrators have been sent to industry.

Space Station 'Freedom'/Columbus

The report submitted on 10 June 1993 to the President of the United States by the 'Blue Ribbon Panel' on the redesign of Space Station 'Freedom' included a section reflecting the International Partners' Assessment on the specific features of the three options and the overall programmatic aspects.

The redesign team has been disbanded after the announcement by President Clinton of the choice of 'Option A' (modular concept utilising a high percentage of Space Station 'Freedom' design and hardware), with some features coming from 'Option B' (deriving directly from Space Station 'Freedom' and utilising close to 100% of its design and hardware).

A transition period, still going on in September, has been decided to finalise the new Space Station configuration and the orbit inclination to be flown.The 'transition team' established (with participation of the International Partners) will also initiate the changes recommended in the areas of NASA management streamlining and the assignment of a single Prime Contractor. To this effect, the Johnson Space Center has been designated as the leader for the Space Station Programme, and Boeing has been nominated Prime Contractor.

Discussions have been held between the Americans and the Russians and an agreement was signed at political level on 2 September 1993 to define a combined Station whereby Russian elements will become part of an International Space Station. A final decision will be taken in November, after consultation with the partners.

Attached Laboratory

The Columbus industrial partners have provided supporting technical inputs to ESA throughout on the impacts of the redesign activity on the Attached Laboratory programme.

The first Subsystems Requirements Review has been held.

A series of Attached Laboratory neutral-buoyancy development tests have been completed successfully in the tank installed at Le Bourget Air Show. Evaluations were performed on hardware modifications incorporated into the payload rack/module interface since the last test series, and on the design features and procedures associated with installation and removal of the controller units on the Attached Laboratory end cone during EVA. In addition to the technical value of these tests, they were also highly appreciated by the members of the public who visited the ESA pavilion during the Air Show, as they were able to watch the tests in progress and were provided with a live commentary and explanations.

A modified programme is now proposed for the Attached Laboratory, to be coherent with the revised Station as proposed, and the reduced budget profile planned in 1994/1995. With a launch date in 2002, the Attached Laboratory is now reduced in length (five Double Racks per side instead of eight) to allow its launch by Ariane-5 with the ATV (Ariane Transfer Vehicle) partially outfitted with payloads. The subsystems will be simplified (e.g. the Data Management System, supporting more autonomous operations), with a Data Relay Satellite (DRS) interface to complement the US TDRSS link and communicate directly with Europe.

The orbital inclination is currently maintained at 28°, but the final choice will depend on the decision concerning the Russian cooperation. Ariane-5 and the ATV would also be charged with the logistics support. This revised approach is now being consolidated.

All the detailed studies and critical developments needed for a launch in 2002 would be performed in 1994/95. The full development effort would then start after the next ESA Council Meeting at Ministerial Level, around the end of 1995.

Precursor flights

The principles for cooperation between ESA and the Russian Space Agency (RKA) have been agreed and the contract for the two Mir flights negotiated and signed.

The four ESA astronauts selected for these 'Euromir' missions (35 days in 1994 and 135 days in 1995), U. Merbold, P. Duque, C. Fuglesang and T. Reiter, have followed extensive Russian language courses, have attended lectures of a general nature and, in August, started their basic training in Star City.

Preparatory studies have been initiated for the E-1 mission on integration and operations tasks.

The final selection of precursor missions will be made later in the year.

Future European Station

Concerning Future Station Cooperation (post Mir-2), a pre-Phase-A concept study for a small free-flying, man-tended laboratory, jointly developed by ESA Member States and Russian industry, for launch around 2003 has started.

Discussions are held at regular intervals in the joint sessions of the ESA/RKA Working Groups covering space stations and space transportation. They have

Metop-1

Programme préparatoire

Des activités initiales ont été mises en route en vue de pousser le développement des instruments ASCAT et MIMR jusqu'au stade des modèles de démonstration technologique, en préparation du programme Métop-1. Des demandes de prix relatives au développement des modèles de démonstration technologique des instruments ASCAT et MIMR ont été envoyées à l'industrie.

Station spatiale Freedom/Columbus

Le rapport remis le 10 juin au Président des Etats-Unis par le 'Blue Ribbon Panel' qui avait été chargé de redéfinir la Station spatiale Freedom comportait une section donnant l'avis des partenaires internationaux sur les caractéristiques spécifiques des trois options et les aspects d'ensemble du programme.

L'équipe chargée de la redéfinition a été dissoute après que le Président Clinton eut annoncé le choix de l'option A (concept modulaire reprenant pour une bonne part la conception et le matériel de la Station spatiale Freedom) plus certains éléments de l'option B (directement dérivée de la Station spatiale Freedom et reprenant presque intégralement sa conception et son matériel). Une période de transition, toujours en cours en septembre, a été décidée pour arrêter définitivement la nouvelle configuration de la Station spatiale et fixer l'inclinaison de son orbite. L'équipe de transition qui a été mise sur pied (avec la participation des partenaires internationaux) mettra également en route les modifications recommandées en ce qui concerne l'allègement de la gestion NASA et le choix d'un maître d'oeuvre unique. A cet effet, c'est le Centre spatial Johnson qui a été désigné pour conduire le programme de Station spatiale, la maîtrise d'oeuvre étant confiée à Boeing.

Les discussions qui se sont déroulées entre Américains et Russes ont débouché le 2 septembre sur la signature d'un accord au niveau politique portant sur la définition d'une station 'combinée' dans laquelle des éléments russes s'intégreront à une station spatiale internationale. La décision finale sera prise en novembre après consultation des partenaires.

Laboratoire raccordé

Les partenaires industriels du projet Columbus ont apporté à l'ESA tout au long de cette période l'appui de données techniques quant aux incidences de la redéfinition sur le programme relatif au laboratoire raccordé.

La première revue des impératifs au niveau des sous-systèmes a eu lieu.

Une série d'essais de développement du laboratoire raccordé a été conduite avec succès en impesanteur simulée dans le bassin qui avait été installé au Salon du Bourget. On y a évalué les modifications matérielles apportées depuis la dernière série d'essais à l'interface entre module et bâti de charge utile, ainsi que les caractéristiques de conception et procédures ayant trait à l'installation et à l'enlèvement des boîtiers de commande sur le cône d'extrémité du laboratoire raccordé pendant les activités extra-véhiculaires. Outre l'intérêt technique qu'ils présentaient, ces essais ont été très appréciés par les visiteurs du pavillon de l'ESA qui ont pu suivre ainsi le déroulement de tous les essais qu'un commentateur expliquait en direct.

Un programme modifié est maintenant proposé pour le laboratoire raccordé, avec pour objectif d'assurer la cohérence avec la station révisée proposée et de prendre en compte le profil budgétaire réduit prévu pour 1994-1995. Le laboratoire raccordé dont le lancement aurait lieu en 2002 est désormais plus court (avec cinq bâtis doubles de chaque côté au lieu de huit) pour pouvoir être lancé par Ariane-5 avec l'ATV (véhicule de transfert Ariane) et une partie de sa charge utile. Les sous-systèmes seront simplifiés (gestion des données par exemple, pour une plus grande autonomie de fonctionnement), et une interface avec un satellite de relais de données (DRS) complétera la liaison avec le TDRSS américain pour communiquer directement avec l'Europe.

On prévoit toujours une orbite inclinée à 28°, mais l'inclinaison qui sera retenue en dernier ressort dépendra de ce qui sera décidé au sujet de la coopération avec la Russie. Ariane-5 et l'ATV seraient également chargés du soutien logistique. Cette nouvelle formule est en cours de consolidation.

En 1994-1995, l'ensemble des études détaillées et travaux de dévelopement critiques à conduire pour un lancement en 2002 seraient exécutés. La réalisation proprement dite démarrerait ensuite après la prochaine session du Conseil de l'ESA au niveau ministériel vers la fin de 1995.

Vols précurseurs

Les principes d'une coopération entre l'ESA et l'Agence spatiale russe (RKA) ont été arrêtés d'un commun accord et le contrat relatif aux deux vols Mir a été négocié et signé.

Les quatre astronautes de l'ESA sélectionnés pour ces missions Euromir (35 jours en 1994, 135 jours en 1995), qui sont U. Merbold, P. Duque, C. Fuglesang et T. Reiter, ont commencé par suivre des cours intensifs de russe et des conférences de caractère général pour entamer ensuite en août leur entraînement de base à la Cité des étoiles.

Les études préparatoires de la mission E1 ont commencé, pour les activités relatives à l'intégration et à l'exploitation.

Le choix final des missions précurseurs interviendra prochainement.

Station européenne future

En ce qui concerne la coopération relative à une station future (post Mir-2), une étude conceptuelle de pré-phase A a été lancée sur un petit laboratoire autonome visitable à réaliser en commun par les Etats membres de l'ESA et l'industrie russe en vue d'un lancement vers 2003.

D'après les échanges de vues qui se déroulent régulièrement dans le cadre des sessions communes des groupes de travail ESA-RKA sur les stations spatiales et le transport spatial, il faudrait que soient élaborées des données sur les besoins en matière de transport spatial du système de station spatiale futur en orbite. Ces données seront utilisées dans des études parallèles portant sur un système de transport spatial commun futur présentant des capacités améliorées par rapport aux véhicules de transport spatial russes actuels.

revealed that input data need to be generated regarding the space transportation needs of the future space station system in orbit. This data will be used in parallel studies for a future joint space transportation system, improving on the capabilities of the current Russian space transportation vehicles.

Studies are being performed for the limited ESA contributions to the Mir-2 space station, at a pre-Phase-A level.

Hermes

Following the guidelines resulting from the ESA Council Meeting in June, the Hermes programme has been re-oriented towards a crew and cargo transportation system based on a non-winged re-entry vehicle, a supporting technology programme, and the servicing elements. The new Programme Proposal will be presented to the Ariane Programme Board for approval.

Technology

A large number of technology study Requests for Proposal had been sent to industry, several of which will not now be performed or will need to be modified in view of the reorientation of the programme. Others remain applicable or require only minor modification. Major changes in the technology programme relate to thermal and mechanical aspects and aerodynamics.

System concepts

The industrial concept studies on non-winged re-entry have identified two types of vehicle for further analysis: a simple capsule and a slender body with bent or bi-conic shape. The Phase Zero System Study proposed as part of the reoriented programme has taken these results into account.

The winged re-entry studies have been completed, and will now be run down. Practically all technical work has been completed for the close-out of the Hermes Baseline, although contractual close-out of the many contract slices is still in progress.

ACRV (Assured Crew Return Vehicle)

The Phase-A study results have been presented to NASA for review. Industry will continue to investigate the sensitivity to changes of critical requirements until the end of 1993. The Phase-B study has been put on hold until a decision can be made on the choice of the new re-entry vehicle-resulting from the Phase-0 study, and clarification of the needs by NASA.

ERA/EVA

The negotiations on the work to be performed on External Robotic Arm (ERA) development during the period 1993–95 are nearly complete. The preliminary proposal for EVA is also being reviewed. Both EVA and ERA benefit from the cooperation with Russia, which has shown interest in using these tools for Mir construction.

ARC (Automated Rendezvous and Capture)

The technical concepts of the ARC target and chaser vehicles have been further defined. Industry is preparing the offer for the Minispas/Astrospas configuration development. Testing of specific hardware and performance simulations are in progress. NASA has failed to secure budget approval for the flight preparation work in 1994, and has announced a delay in the launch date to 1998.

ATV (Automated Transfer Vehicle)

The ATV has passed a joint configuration review and the technical interchange team has established the compliance with the present Space Station requirements and has established design reference missions.

New missions for the ATV, like the transfer of a manned vehicle, of the APM to the SSF, or the servicing of Mir-2 will be studied with the support of industry.

The Phase-B study has been delayed until a decision can be taken in mid-1994 on the technical options for the programme.

Ariane-5

System

Two important system events should be noted:
- in Guiana, an HI55 stage was assembled for the first time on two pylons simulating the P230s. Following the integration, the launch table bearing the composite, almost 32 metres tall, was taken out of the launcher integration building to the rail track leading to the final assembly building;
- in Europe, the launcher's electrical systems are now being integrated in The Ariane-5 functional simulation facility.

P230 solid-booster stage

The M1 test, the first teststand firing of the Ariane-5 solid booster using an actual flight structure, took place very successfullv on 25 June. The measurements taken and inspections carried out after the test show that all the equipment, and the joints in particular, performed to a very high standard. As preparations for the M2 specimen are well under way, a test in mid-November can be envisaged.

Equipment qualification is continuing in Europe for the distancing rockets and the nozzle actuation units. Qualification tests on the rear skin have ended and the results are in line with predictions.

H155 stage

All the hardware for the battleship stage tests in Guiana has been acceptance-tested and the thrustframe fitted with its fluid and electrical systems is nearing the end of the integration process.

The tank to be used during development and qualification tests on the H155 stage is nearing completion and welding of the tank for flight 501 has almost finished.

The Vulcain engine has undergone 148 tests, amounting to 30 700 seconds burntime. It should be noted that the first flight-rated engine recently underwent four tests accounting for over 2200 seconds in all, which is equivalent to four flights.

L9 stage and fairing

The stage to be used for the propulsion system development tests is being integrated. This will mean that the first firing can take place in October.

The first fairing separation test took place in July in the United States and the second is currently planned for the end of the year.

Des études de pré-phase A sont en cours sur les contributions limitées de l'ESA à la station spatiale Mir-2.

Hermes

En application des directives élaborées à l'issue de la session du Conseil de l'ESA en juin, le programme Hermes a été réorienté vers un système de transport d'équipages et de cargaisons basé sur un véhicule de rentrée atmosphérique sans voilure, un programme de soutien technologique et des éléments de desserte. La nouvelle proposition de programme sera soumise à l'approbation du Conseil directeur du programme Ariane.

Technologie
Parmi les nombreuses demandes de propositions d'études technologiques qui ont été envoyées à l'industrie, plusieurs vont maintenant rester sans suite ou devront être modifiées pour tenir compte de la réorientation du programme. Les autres demeurent applicables ou n'exigent que des modifications mineures. Les principales modifications apportées au programme technologique ont trait aux aspects thermiques et mécaniques et à l'aérodynamique.

Concepts système
Au vu des résultats des études de concept réalisées dans l'industrie sur les véhicules de rentrée sans voilure, il apparaît que deux types de véhicules méritent un complément d'analyse: l'un est une simple capsule, l'autre présente une configuration élancée de type émincé ou biconique. Ces résultats ont été pris en compte dans l'étude système de phase zéro qui a été proposée dans le cadre du programme réorienté.

Les études sur les systèmes de rentrée à voilure ont été menées à terme et vont maintenant être arrêtées. Pratiquement toutes les activités techniques ont été achevées pour la clôture de la référence Hermes, même s'il reste encore à clore officiellement de nombreuses tranches de contrat.

ACRV (Véhicule de secours pour le retour de l'équipage)
Les résultats de l'étude de phase A ont été présentés à la NASA pour examen. L'industrie continuera d'étudier jusqu'à la fin de 1993 la sensibilité aux modifications de certaines exigences critiques. L'étude de phase B a été suspendue jusqu'à ce qu'une décision puisse être prise quant au choix du nouveau véhicule de rentrée résultant de l'étude de phase zéro et dans l'attente de précisions sur les impératifs de la part de la NASA.

ARC (Rendez-vous et capture automatiques)
La définition des concepts techniques du véhicule cible et du véhicule chasseur pour l'ARC s'est poursuivie. L'industrie prépare actuellement l'offre relative à la mise au point de la configuration Minispas/Astrospas. L'essai du matériel spécifique et des simulations de fonctionnement sont en cours. La NASA n'a pas obtenu l'approbation du budget pour les activités de préparation aux vols en 1994 et a annoncé un report de la date de lancement à 1998.

ATV (Véhicule de transfert automatique)
L'ATV a subi avec succès une revue conjointe de configuration et l'équipe chargée des échanges techniques a constaté la conformité du concept avec les impératifs actuels de la Station spatiale et a défini les missions de référence.

De nouvelles missions de l'ATV, comme le transfert d'un véhicule habité, le transfert de l'APM à la SSF, ou la desserte de Mir-2, seront étudiées avec le soutien de l'industrie.

L'étude de phase B a été reportée jusqu'à ce qu'une décision puisse être prise à la mi-1994 sur les options techniques du programme.

Ariane-5

Système
Deux événements importants concernant le système Ariane-5 doivent être signalés:
- *en Guyane, pour la première fois, un étage H155 a été assemblé sur les deux pylônes simulant les P 230. A l'issue de cette intégration la table de lancement qui supporte ce composite de près de 32 m de haut, a été sortie du Bâtiment d'Intégration Lanceurs (BIL) pour rejoindre la voie ferrée menant vers le Bâtiment d'Assemblage Final (BAF);*
- *en Europe l'ensemble des systèmes électriques du lanceur est désormais intégré dans l'installation de simulation fonctionnelle d'Ariane-5.*

Etage à poudre P 230
L'essai M1, premier tir au banc du propulseur à poudre d'Ariane-5, avec une structure identique à celle du vol, s'est déroulé de façon très satisfaisante le 25 juin. Les mesures effectuées et les expertises conduites après l'essai démontrent l'excellent comportement de l'ensemble des matériels, notamment l'ensemble des liaisons. La préparation du spécimen M2 est très avancée, ce qui permet d'envisager un essai vers la mi-novembre.

Par ailleurs, en Europe, les qualifications de matériels se poursuivent comme pour les fusées d'éloignement et les groupes d'activation tuyère. Quant à la jupe arrière, les essais de qualification sont terminés et conformes aux prévisions.

Etage H 155
Tous les matériels destinés aux essais du banc étage lourd en Guyane sont recettés et le bâti-moteur équipé de ses systèmes fluides et électriques est en fin d'intégration.

Le réservoir qui sera utilisé lors des essais de mise au point et de qualification de l'étage H 155 est en cours de finition et le soudage du réservoir du vol 501 est quasiment terminé.

Le moteur Vulcain en est à 148 essais cumulant plus de 30 700 s de fonctionnement. Il faut remarquer que le premier moteur conforme au standard de vol vient de réaliser en quatre essais plus de 2200 s cumulées, soit presque l'équivalent de quatre vols.

Etage L9 et coiffe
L'intégration de l'étage destiné aux essais de mise au point du système propulsif est en cours, ce qui permettra une première mise à feu courant octobre.

Le premier essai de séparation de la coiffe s'est déroulé en juillet aux Etats-Unis et le second est actuellement prévu d'ici la fin de l'année.

In Brief

Olympus Satellite Retired

ESA has terminated the mission of its experimental Olympus telecommunications satellite and moved it out of the geostationary orbit to a lower orbit to minimise the probability of it hitting other spacecraft.

During the night of 11/12 August, service from Olympus was interrupted for reasons that may never be fully known, and the satellite lost its Earth-pointing attitude and began spinning slowly. This event and the subsequent activities to retrieve the satellite used the last few kilograms of fuel remaining on board. The Agency therefore assessed that it would not be possible to re-establish service and began the re-orbiting process. It was decided to re-orbit to a lower rather a higher altitude because the incident itself caused an orbital perturbation in this direction and, consequently, there would not have been sufficient fuel to re-transfer the spacecraft to a higher orbit. Once the satellite had reached the lower orbit, several end-of-life tests were then conducted and the pressurant remaining in its tanks was depleted. With the satellite in this 'safe' configuration, Olympus was turned off and its mission ended.

The Olympus satellite

Olympus was launched in 1989 to conduct experiments in, among other areas, direct broadcasting and video conferencing. It was expected to remain in operation until July 1994 but it had conducted 80% of its tasks.

Among its many uses, Olympus has been instrumental in the development of distance learning satellite applications — over 100 organisations in 12 countries have used Olympus to develop training courses which have become part of the established satellite-based educational infrastructure. Several of those operations have now been transferred to the Eutelsat space segment.

In the broadcasting field, Olympus was the initial test bed for a number of satellite-broadcast programmes that are now running on a commercial basis, including the BBC World Service and Raisat. It was also used for experimental broadcasts in the development of high definition TV.

During late 1992 and the first part of this year, the satellite was used in establishing a data relay link with data being transmitted from the Eureca satellite in low Earth orbit to Olympus and then to Earth. This was the first time that such a transfer had occurred in Europe and the first such transfer in the world using the Ka frequency band.

New Head of ESA Office in Guiana Appointed

The Director General of ESA has appointed Maurice Delahais as Head of the ESA Office in French Guiana, as of 6 September.

Mr Delahais, of French nationality, joined ESA in 1967. He was the Head of the Scientific Projects Departments at ESTEC (in Noordwijk, The Netherlands) for 12 years before becoming the Head of ESA's Hermes Office and Future Programmes in 1988.

Maurice Delahais, the new Head of the ESA Office in French Guiana

Ariane-5 Roll-Out

The first flight-type H155 cryotechnic stage, the main engine for the Ariane-5, was rolled out of the Launcher Integration Building on the Ariane-5 launch table, at ESA's launch site in Kourou, French Guiana on 18 September. It was flanked by two P230 solid booster mock-ups.

This cryotechnic stage is part of an essential campaign of the Ariane-5 development programme called the Operational Deployment Programme. During this campaign, all operations relating to the transport, handling and assembly of various elements of the launcher will be validated and the associated ground support systems will be qualified.

The members of the Ariane Programme Board, in Kourou to attend the Board's 134th meeting, witnessed the event. Approximately 150 European industrialists representing most of the companies involved in the construction of the Ariane-5 ground infrastructure in Kourou, were also present.

The members of the Ariane Programme Board in front of the first flight-type H155 cryotechnic stage to be used on Ariane-5. It is flanked by two mock-ups of the P230 solid boosters.

ESA Participates in 44th IAF Congress

On 16–22 October, ESA participated in the exhibition held in conjunction with the 44th Congress of the International Astronautical Federation (IAF) in Graz, Austria. More than 1300 space experts from around the world met at the Congress to discuss technological achievements and plans for the future of the world's space programmes.

The International Space Exhibition was open to the public for four days and approximately 11 000 people, in addition to the Congress participants, visited the stands.

The opening of the IAF exhibition. From left to right: Prof. J. Ortner, Director of the Austrian Space Agency; A. Stingl, Mayor of Graz; J.-M. Luton, Director General of ESA; and K.-E. Reuter, Head of ESA's Cabinet.

25 Years of ESRO-1/Aurorae

Twenty-five years ago, on 3 October 1968, ESRO-1/Aurorae was launched from Vandenburg Air Force Base in California. ESRO-1/Aurorae was the second successful launch made by the European Space Research Organisation (ESRO), which later merged with the European Launcher Development Organisation (ELDO) to become the European Space Agency (ESA).

The 85.7 kg satellite carried eight experiments to explore the ionospheric phenomena relating to the Northern Lights or Aurora Borealis. The satellite was launched by a Scout rocket into an elliptic, polar orbit with an apogee of 1533 km and a perigee of 258 km. It was magnetically oriented, i.e. it aligned itself tangentially to lines of the magnetic field of the Earth.

The development of ESRO-1/Aurorae began in 1964, with the successful launch following only four years later. The main participating firms were the Laboratoire Central de Télécommunication (LCT) of France as prime contractor for overall management, housekeeping and electrical integration; Contraves AG (now Oerlikon Contraves) of Switzerland for structural, mechanical and thermal evaluation and stabilisation; and Bell Telephone Manufacturing Company of Belgium for power supply.

To celebrate this silver jubilee, Oerlikon Contraves invited the members of the former ESRO-1 team — ESRO staff, contractors and experimenters — to their premises in Zurich. The host was H.P. Schneiter who, in the ESRO days, was responsible for the structure and mechanism of the spacecraft and is now Director of Business Unit Space at Oerlikon Contraves. He and his staff invested a great effort, not only in organising the event, but also in collecting the addresses of the former ESRO-1 team members, some of whom have retired and many of whom have dispersed across Europe.

The reception following the welcoming addresses. From left to right: A. Menth, Chief Executive Officer, Oerlikon-Contraves; D.E. Mullinger, ESRO-1 Project Manager; G. Phelizon, ESRO-1 Project Manager at LCT. Behind them, are two former ESRO-1 experimenters: S. Olsen and G. Skovli.

Seventy-one former members of the team joined the celebration on 1 October, with some experimenters coming from as far away as Kiruna, Sweden and Bergen, Norway. The celebration began with a reception, with welcoming addresses given by Mr. Schneiter, D.E. Mullinger (the former ESRO-1 Project Manager) and G. Phelizon (the former Project Manager for ESRO-1 at LCT). A film on ESRO-1 brought back memories of the work done more than a quarter of a century ago.

The participants also visited the facilities of Oerlikon Contraves' Business Unit Space where they were shown the manufacturing of Ariane 4 and Ariane 5 rocket fairings, the Cluster structure, and an engineering model of the Huygens re-entry cone — an impressive demonstration of that company's modern carbon fibre technology.

The reunion culminated in a dinner in Swiss-country style surroundings, at which the ESRO-1 family was joined by P. Creola, head of the Swiss Delegation to the ESA Council, and J.P. Ruder, member of the Swiss Delegation. This concluded a memorable event for all participants — they relived old memories, the efforts expended, and the problems solved which resulted in the successful mission of ESRO-1/Aurorae giving new scientific data on the Aurora Borealis.

M.G. Grensemann

Seventy-one members of the ESRO-1 family gathered at Oerlikon-Contraves to celebrate the 25th anniversary of the ESRO-1/Aurorae launch

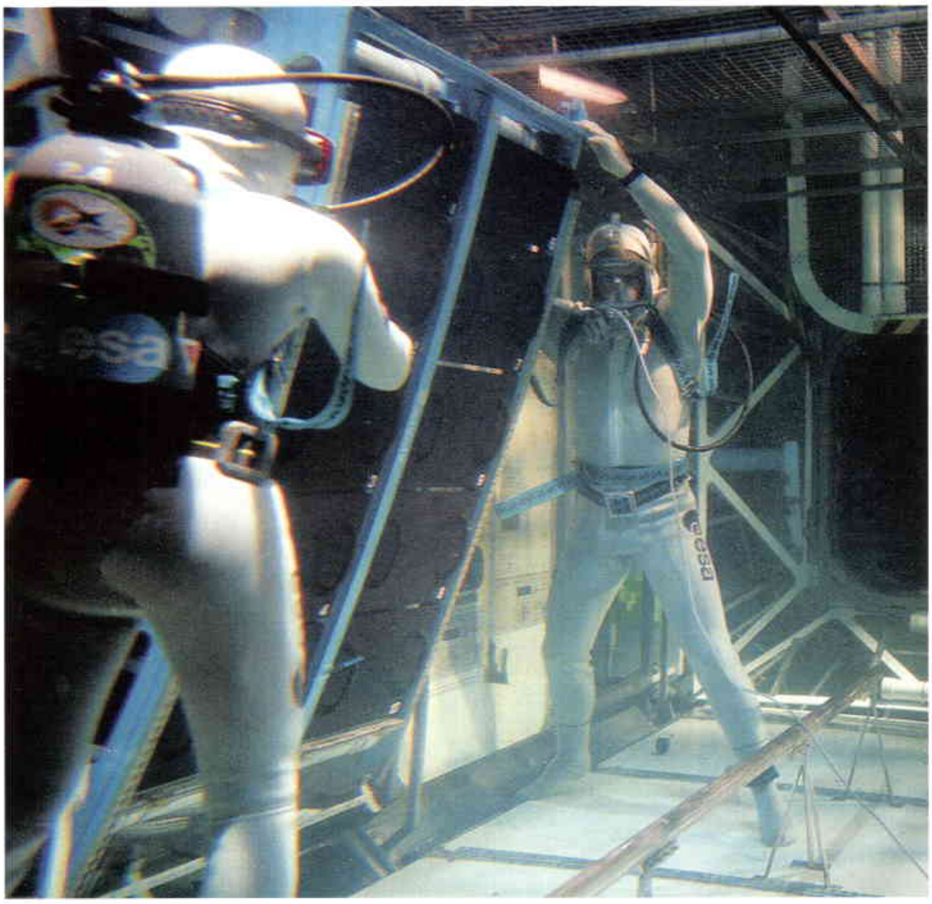
Underwater Testing at Le Bourget Air Show

During long-term missions, a space station's subsystems and payload equipment will need to be maintained and serviced in orbit. To evaluate the maintenance and servicing tasks that crewmembers will have to carry out under microgravity conditions, ESA's Columbus Crew Office has been conducting underwater simulations of the activities in public swimming pools, using a mock-up of the Columbus Attached Laboratory. This zero-gravity environment allows both engineers and astronauts to fully understand the effects of microgravity on the design of equipment and on the method of working in microgravity — tasks that are routine on Earth are much more difficult when wearing a space suit and bulky gloves, and when the tools and hardware float away.

The most recent underwater simulation was conducted at the Le Bourget Air Show in Paris in June. ESA erected a giant aquarium that allowed members of the public visiting the ESA pavilion to watch 'astronauts' performing actual underwater tests using the Attached Laboratory mock-up.

The tank containing the Attached Laboratory mock-up, at the Le Bourget Air Show

In this simulation, the team assessed the location and type of aids such as handles and foot restraints that are required both inside and outside the module to allow the crew to remain in one place while working or to assist them in moving around. They determined that it is essential to have a central banister along the corridor of experiment racks to allow both crew mobility and restraint. It is also necessary to have a portable workbench that can slide along the banister to the location at which the astronaut is working. The workbench could consist of a work surface, a tool caddy and drawers for storing other equipment. A portable PC (for payload operations) and a terminal (for system operations) could be attached to the workbench.



The procedures for the installation and handling of racks containing experiments and other equipment were tested and streamlined. Some equipment and hardware that requires servicing, such as plumbing or heating systems, is located beneath or behind the racks or in the module's end cones and is difficult to access. During the simulation, the best method of working on that equipment was identified and tested.

The team tested two suits used for 'space walks' or Extra Vehicular Activities (EVA) — one was developed by ESTEC and is volumetrically representative of the suit used by NASA, the other was developed for French-Russian Mir mission training. The team's objectives were to begin to understand the difficulty of working while wearing such a suit and to study the ergonomic aspects of each suit, for example, how comfortable the

Divers practise removing a rack from the mock-up in the diving tank at the Le Bourget Air Show astronaut is within the suit, the level of visibility when wearing the helmet, the degree of flexibility of the joints and upper limbs, and the general constraints on mobility.

In addition, the method of installing and removing hardware that is on the outside of the module and is often large or bulky, while wearing an EVA suit, was tested. The team found that it is necessary to have good indicators of where the equipment is to be placed, given that the astronaut is wearing a helmet and could have limited vision and is also wearing gloves. The hardware being installed and the tools being used tend to float away; it is therefore necessary that they are tethered or that a method of temporary stowage is provided. The location of handles and mobility and foot restraints was also found to be critical.

This underwater simulation has demonstrated again that, with the proper equipment, the testing of maintenance and servicing activities can be conducted in a very cost-effective way.

ESA staff members Carlo Viberti (left) training in the Russian EVA suit and Pete Colson (right) in the ESTEC-development EVA suit.

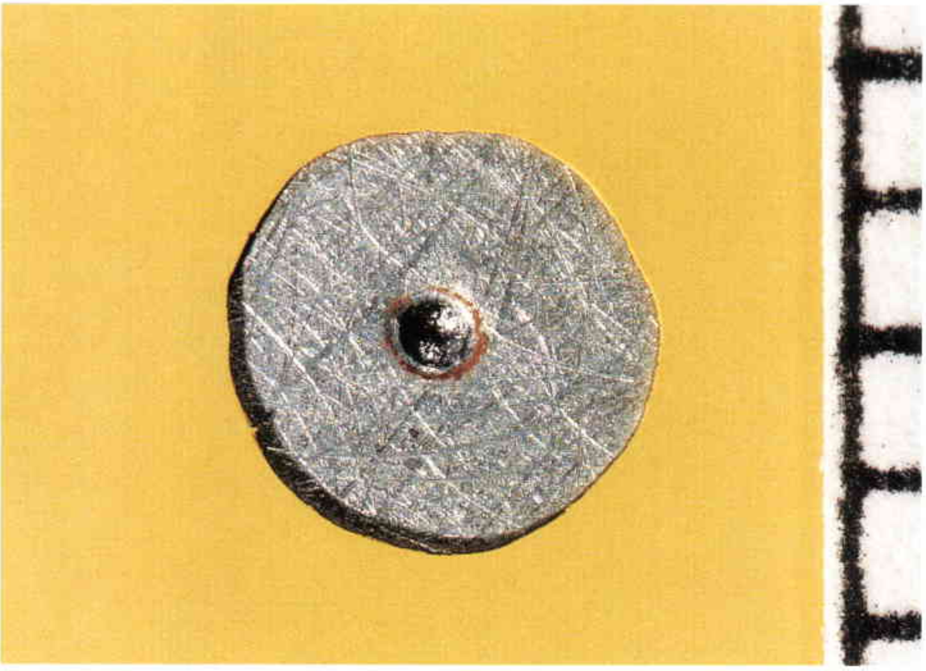
Meteoroid/Debris Damage to Eureca Being Analysed

The European Retrievable Carrier (Eureca) was retrieved by the Space Shuttle in June 1993 and returned to Earth after almost 11 months in orbit. Its return provided a unique opportunity to study the effects of the space environment on spacecraft components and materials. ESA has taken this opportunity and initiated a Eureca post-flight investigation programme.

Eureca had about 145 m^2 of exposed external surfaces, including 99 m^2 of solar arrays (front and rear). The orbit was nearly circular at 28.5 degrees inclination and had an initial altitude of around 510 km.

Impact craters caused by hypervelocity collisions with meteoroids and space debris particles are some of the most noticeable features on Eureca's surfaces. To document and analyse these impact features, a complete optical survey of all outer surfaces is being performed. In addition to a large number of impacts on the solar arrays, about 90 impacts have been clearly identified on the main Eureca body, including a 2 mm diameter hole penetrating the ESA/ERNO sign plate.

Material contamination and degradation, and the effects of UV radiation and the residual atmosphere (mainly atomic oxygen) are other interactions to be studied in detail as part of the Eureca Post-Flight Investigation Programme.



An impact feature on a Eureca scuff plate. The crater in the centre is about 0.5 mm in diameter. The circular patch around it where the paint has been removed by the impact is about 3 mm wide.

F. Engström (seated, left), ESA Director for Space Station and Microgravity, and J.J. Dordain (right), ESA Associate Director of Strategic Planning and International Policy, answer questions during the ESA press conference at Moscow Aerospace '93. The ESA stand is behind them.

One Million Orbital Elements Now in Space Debris Database

The number of orbital elements, i.e. parameters that describe an orbit, recorded in ESA's space debris database surpassed the one-million mark in October.

The database, named the Database and Information System Characterising Objects in Space (DISCOS), was created in 1990 to support research work in the area of space debris. Institutes and national space centres in several Member States regularly retrieve orbital and physical information (radar cross-section has been added recently) on some of the 22 800 objects launched since 1957. Every month, 25 000 orbital elements are added to the database. The U.S. Space Surveillance Network generates these elements for the approximately 7000 objects that it is currently tracking. The tracked objects consist of functioning and decommissioned satellites, upper stages of rockets, and fragments from breakups in orbit.

DISCOS is maintained by the European Space Operation Centre (ESOC) in Darmstadt, Germany. For further information, contact:

Walter Flury
ESOC
Darmstadt
Germany
Tel: 49-6151-902270

ESA at Moscow Aerospace '93

From 31 August to 5 September, ESA participated for the first time in Moscow Aerospace '93, an international trade fair on aerospace and aviation. Other space agencies and leading aerospace companies from 14 countries including Russia itself, the USA, and Eastern and Western European countries were also present.

The ESA stand featured an exhibition on its current programmes, particularly its Earth observation and space transportation systems, and highlighted the Agency's cooperation with Russia.

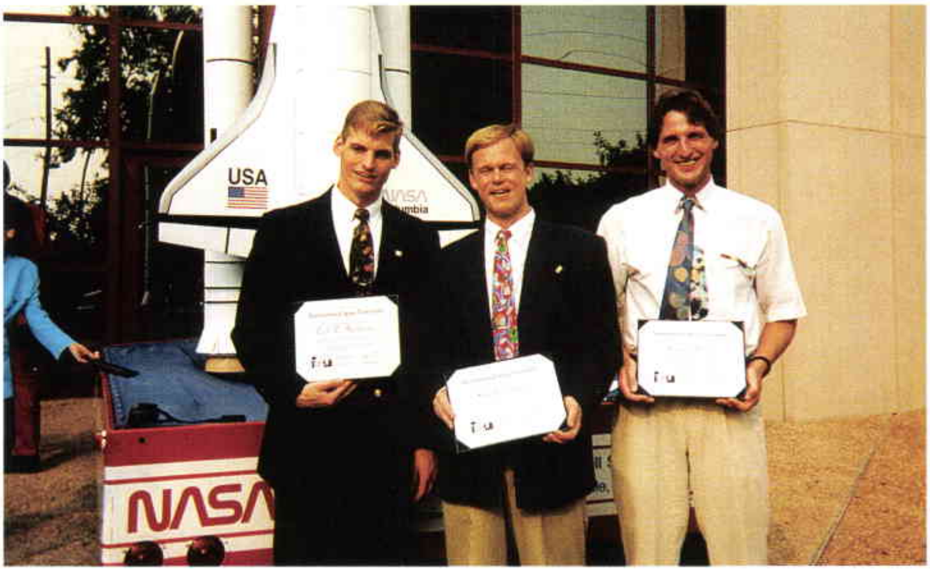
The stand was located among those of Russian institutions and companies, upon Russia's invitation.

In demonstration of its relationship with Russia, ESA formally presented its four ESA astronauts who are currently training in Star City for participation in the upcoming EuroMir flights. Two of them, Ulf Merbold and Pedro Duque are preparing for the 30-day EuroMir '94 mission on board Mir, scheduled for launch in September 1994. The other two, Christer Fuglesang and Thomas Reiter are preparing for the 135-day EuroMir '95 mission, scheduled for launch in August 1995.

Approximately 70 000 members of the public and 50 000 professionals, including many leaders of Russian government and industry, visited the air show.

The four ESA astronauts training in Star City for participation on EuroMir flights. From left to right: Ulf Merbold, Christer Fuglesang, Pedro Duque and Thomas Reiter.

International Space University Holds 6th Summer Session



Three new ISU alumni, from left to right: Ted Ashburn (MIT), Per Osterman (ESA/ESTEC), and Rüdiger Jehn (ESA/ESOC)

More than 100 students from 30 countries gathered in Huntsville, Alabama, to attend the ISU summer programme.

The ISU is a non-profit, educational institution specialising in advanced, space studies programmes. Its primary goals are to identify, assemble and educate talented graduate students and young professionals, to offer them a space-related curriculum, and to expand and enhance international collaboration for the peaceful use of outer space.

The first summer session was held at the Massachusetts Institute of Technology (MIT) in Cambridge (USA) in 1988. Since then, it has been held in Strasbourg, France in 1989; Toulouse, France in 1990; Montreal, Canada in 1991; and Kitakyushu, Japan in 1992.

Each year, ESA sponsors a group of Europeans, including two ESA staff members, to attend ISU. This year, the two ESA staff members were Rüdiger Jehn from ESOC and Per Österman from ESTEC.

The ISU summer session lasts 10 weeks. Experienced professionals from all spacefaring nations, including researchers, astronauts and cosmonauts, teach courses or give lectures, and are available for the exchange of ideas. Some of the astronauts preparing for the Hubble Space Telescope servicing mission, for example, took time out of their training to speak about their up-coming tasks. Several ESA staff members were also among the teaching staff.

During the first five weeks of the programme, the curriculum encompasses core lectures in 10 fields of study ranging from space architecture and life sciences to space business and management, and policy and law. After completing those courses, the students had to choose one of the 10 areas for more in-depth study.

Each student also had to select one of two design projects — they must design a specific space system taking into account all aspects including the ground segment, space segment, communication, funding, management policy, legal issues, and social and environmental impacts.

Two design projects were undertaken this year: an observatory on the far side of the Moon, and a global disaster warning and mitigation system named GEOWARN. The latter project is still underway: the students are now working on its realisation (see full article in the next issue of the ESA Bulletin).

Field trips are also considered an essential element of the ISU programme. In addition to sidetrips to the beaches of the Gulf of Mexico and experimentation in New Orleans' Cajun restaurants, the students took advantage of the nearby academic and space-related facilities, which include NASA's Marshall Space Flight Center (MSFC), the Alabama Space and Rocket Center, and Cummings Research Park. Some students trained in MSFC's neutral buoyancy tank, where each learnt the challenges of working in a low gravity environment. All students witnessed the test firing of improved Space Shuttle main engines, which are developed at MSFC.

Upon graduation, each student was presented with a a personally dedicated flag that had flown in space aboard the Space Shuttle, as a gift from MSFC for their participation in ISU. The next summer session will be held in Barcelona in June 1994.

The 100 students from 30 countries at this summer's ISU programme in Huntsville, Alabama

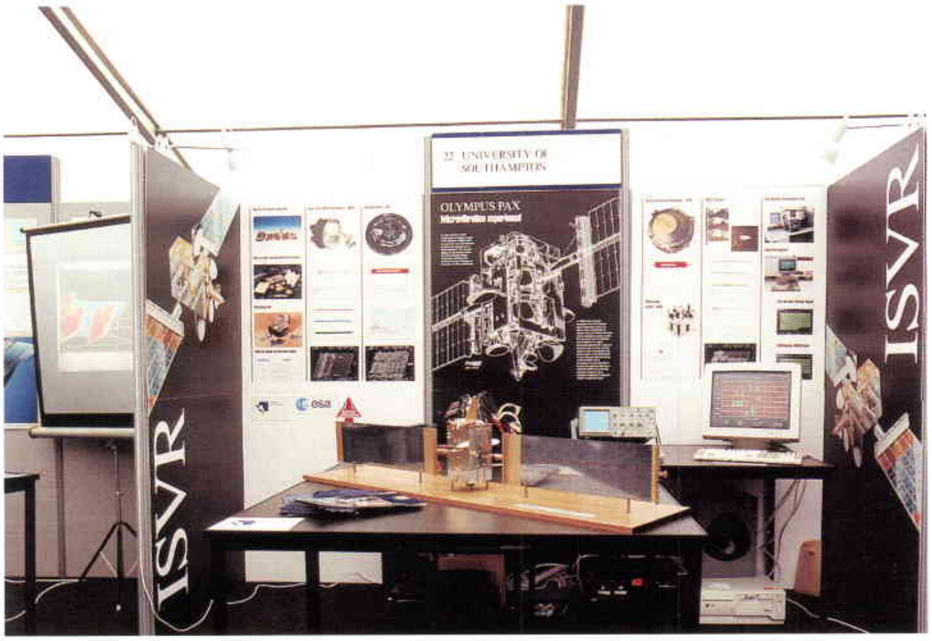
ISVR Demonstrates Satellite 'Health-monitoring' System

The 1993 Royal Academy of Engineering (UK) Soirée was held at Imperial College in London on 22 June in the presence of the Royal Fellow, HRH The Duke of Kent. The theme of the exhibition, 'The contribution of university engineering research to success in industry', was broadly interpreted leading to some 30 exhibits from British universities.

The Institute of Sound and Vibration Research (ISVR) at the University of Southampton (UK) collaborated with ESA's space research and technology centre, ESTEC, on an exhibition on applications of vibration data from a geostationary satellite in orbit based on a recent experience with a vibration measuring payload on ESA's Olympus satellite. The stand enabled delegates to hear recordings of audio bandwidth satellite vibration during an east-west station-keeping manoeuvre and to see some statistical analysis of the vibration data. Engineering models of satellite mechanisms, which had been provided by British Aerospace, the prime contractor for Olympus, were also displayed.

The collaborative research programme between ESTEC and ISVR has shown ways of exploiting vibration data for the monitoring of the 'health' of a satellite's mechanical systems while in orbit. A highly sensitive accelerometer package measures the very small vibrations caused by the operation of on-board systems. The signals are transmitted to Earth where they can be analysed in real time or recorded for future analysis. ISVR assembled and programmed a digital signal-processing, enhanced PC system using algorithms developed at ESTEC which enabled the monitoring of the signal from Olympus to be carried out for several months.

A more refined 'health-monitoring' system currently under consideration for future spacecraft could increase the operational lifetime of satellites by predicting component failures and could contribute ultimately to improved component design.



The ISVR stand at the 1993 Royal Academy of Engineering Soirée.

ESA Signs New Agreement With Finland

On 25 August, ESA and Finland signed an agreement covering FInland's participation in ESA's General Support Technology Programme (GSTP), the primary objective of which is to develop identified critical technologies.

Under this agreement, Finland's involvement is to be focused in particular on studies concerned with Earth/space telematics networks, deep space observatory facilities, and global Earth monitoring.

As an Associate Member of the Agency, Finland is already contributing to the Agency's science, Earth observation and telecommunications programmes, and has opened negotiations with ESA on the formalities required for it to become a full Member State.

Mr Jean-Marie Luton, Director General of ESA (left), and His Excellency Matti Hakkanen, Finnish Ambassador to Paris (right), sign the agreement covering Finland's expanded involvement in ESA activities

PIERS 1994

Progress in Electromagnetics Research Symposium
European Space Research and Technology Centre
ESTEC, Noordwijk,The Netherlands
11-15 July 1994

esa
european space agency
agence spatiale européenne

FIRST CALL FOR PAPERS

The 1994 Progress in Electromagnetics Research Symposium will be organized by the European Space Agency (ESA) at the European Space Research and Technology Centre (ESTEC) on 11-15 July 1994, in Noordwijk, The Netherlands.

PIERS provides an international forum for reporting progress and recent advances in the modern development of electromagnetic theory and its new and exciting applications. For the first time, PIERS will take place outside the USA. The main emphasis will be on recent development of electromagnetic research for remote sensing and space applications but consideration will be given to papers on other subjects.

Symposium Organization

PIERS'94 General Chairman: Mr. Marius Le Fevre, Director, ESA/ESTEC, Noordwijk (NL)
PIERS Chairman: Prof. Jin Au Kong, 26-305, MIT, Cambridge, MA 02139 (USA)
PIERS'94 Technical Chairman: Mr. Bertram Arbesser-Rastburg, ESA/ESTEC (NL)
Conference coordination: Mrs. Gonnie Elfering and Mr. Pieter van Beekhuizen, ESA/ESTEC (NL)
Local arrangements and symposium program and proceedings publication: Messrs. Maurice Borgeaud, J.P.V. Poiares Baptista, Josef Noll, and Sergio Buonomo, ESA/ESTEC (NL)

Suggested Topics Include

- Active remote sensing: radar polarimetry, surface and volume scattering, retrieval algorithms, interferometry.
- Passive remote sensing: optical/microwave, radiometry, polarimetry, inversion techniques, scattering.
- Wave propagation: theory, ionosphere, atmosphere, mobile, other planets, non-linear effects, plasma.
- Antennas: theory, microstrip, multi-layer, reflector and array antennas, analysis, synthesis and measurements.
- Devices and materials: millimetre, sub-millimetre, and optical devices, composite and chiral media.
- Electromagnetic theory: computational EM, methods and techniques, applications, fractals.
- Electromagnetic compatibility: system analysis tools, verification methodology, statistical approaches.

ABSTRACTS MUST BE RECEIVED BY 17 DECEMBER 1993

Prospective authors are invited to submit a one-page abstract of no less than 250 words no later than 17th December 1993. The abstract should explain clearly the content and relevance of the proposed contribution with complete names and affiliations of all authors. Authors are requested to present no more than three papers.

ACCEPTANCE NOTIFICATION BY 18 FEBRUARY 1994
SYMPOSIUM PROGRAM AND INFORMATION SENT BY 18 MARCH 1994

Acceptance notification will be mailed by 18th February 1994 to the corresponding author of the submitted contribution and symposium program and information will be mailed by 18th March 1994 together with travel and accommodation information. Though it is not in the PIERS tradition, a full-length paper (maximum 4 pages) is requested by ESA and should be sent no later than 20th May 1994.

FULL-LENGTH PAPERS BY 20 MAY 1994

Advance registration fee for all participants, including session chairmen and authors, is NLG 500 (Dutch Guilders) if payment is received before 20th May 1994. After this date and during the meeting, the registration fee will be increased to NLG 600. The fee includes the reception, dinner, attendance at all sessions, refreshments, the Symposium program, abstracts, and the proceedings. Correspondence and abstracts should be sent to:

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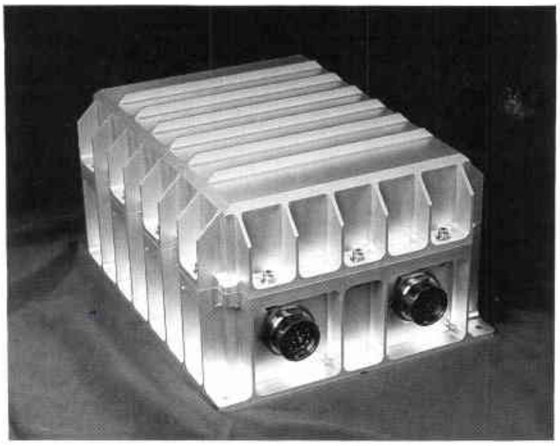
AMP TEK®

SPACEFLIGHT DATA RECORDER

FDR-8000

Product Spotlight

Model:	FDR-8500C
Capacity:	5 Gigabytes (uncompressed)
	10 Gigabytes (2:1 compression)
	250 Gigabytes (50:1 compression)
Date Rate:	10 Mbit/s per channel (burst)
	4 to 12 Mbit/s total (sustained)
Weight:	16 lbs (7.3 kg)
Power:	18 Watts @ 28VDC
Size:	11.8" x 9" x 6"
	(300mm x 229mm x 152mm)
Interface:	RS-422



FDR-8000 series recorders are flight-proven, high performance data storage units built for operation within the Space Shuttle bay, on the aft flight deck, and aboard space platforms. Designed with 8mm helical scan technology, the FDR-8000 line provides economical mass data storage. These recorders' unique characteristics make them equally useful in avionics and satellite applications.

Capacity

The newest member of the FDR-8000 family is the FDR-8500C. The capacity of the FDR-8500C is 5 Gigabytes of uncompressed data. Hardware compression is typically 2:1, yielding 10 Gigabytes of storage space. Depending on data content, compression rates of 50:1 are attainable. Peak data rates are 10 Mbit/s per channel into a 4 Mbit buffer. Multiple input models are available. Total sustained data rates from combined channels are from 4 Mbit/s to 12 Mbit/s depending on compression efficiency. The error rate is less than one in 10^{13} bits read.

Mechanical

The FDR-8000 enclosure is a sealed box purged with nitrogen. The inert gas provides an air cushion around the recording head and protects the tape from common corrosive gases during long term storage. Internal heaters activate below +10°C. During initialization, recording is disabled until heaters can stabilize the internal environment above 0°C. Shock and vibration isolation allow the tape transport assembly to surpass Shuttle launch and landing requirements.

The recorder's footprint measures 11.8" x 9" (300mm x 229mm), with a height of 6" (152mm). The mounting hole pattern is on 70mm centers for easy interfacing with ESA cold plates and Hitchhiker pallets. Total weight is 16 lbs (7.3 kg).

Electrical

Power dissipation is 18 Watts at 28V. Each recorder contains its own DC/DC power converter. An internal controller supports serial data transfer, file structures, error recovery, and regulation of the recorder's operating environment.

Interface

Communication with the FDR-8000 is provided via RS-422 compatible channels. The command channel is asynchronous at 1200 baud. The data channel is synchronous from DC to 10 MHz.

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