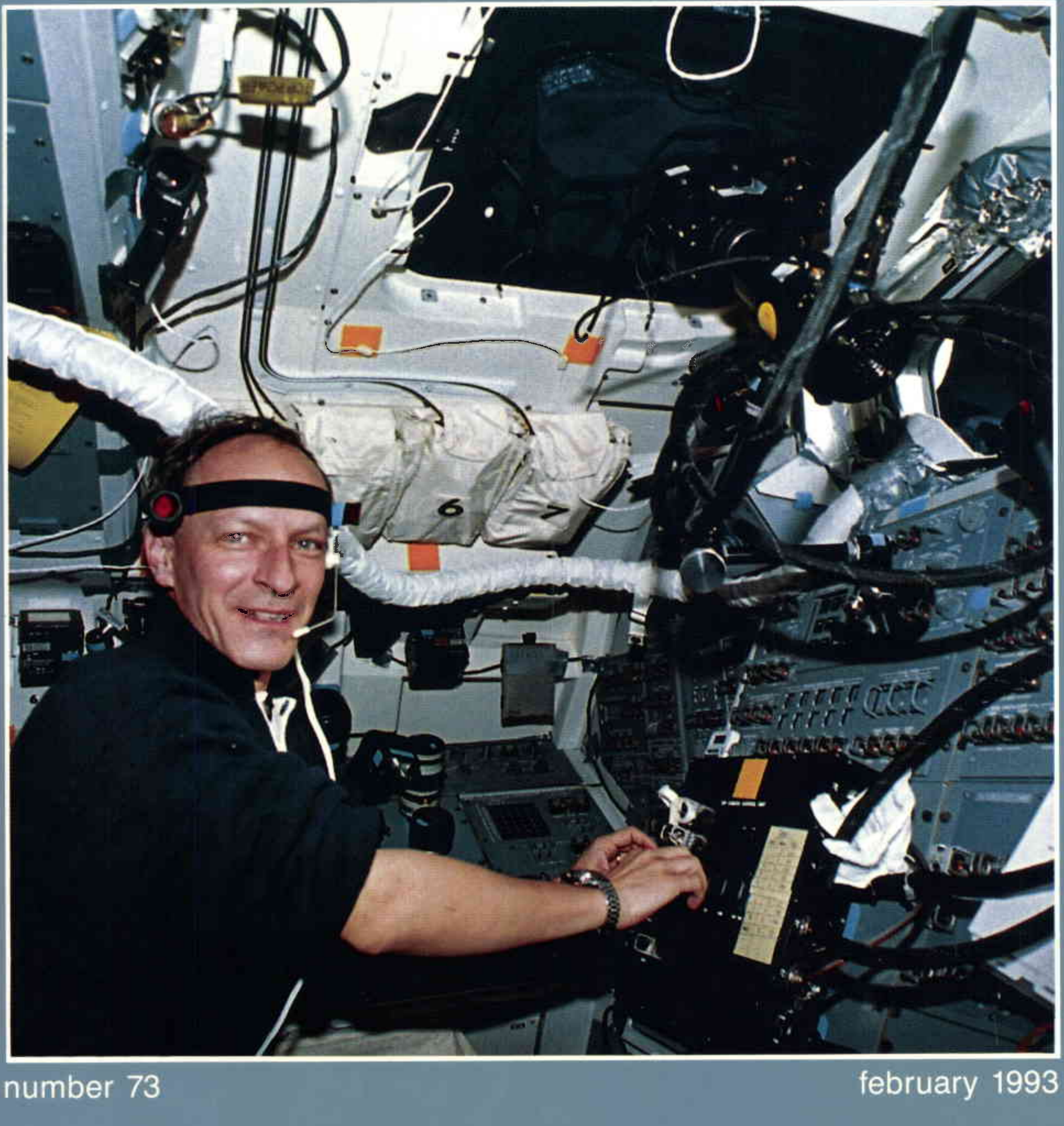
european space agency

esa bulletin

agence spatiale européenne



number 73

february 1993

european space agency

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

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

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

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

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

The ESA HEADQUARTERS are in Paris.

The major establishments of ESA are:

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

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

ESRIN, Frascati, Italy.

Chairman of the Council: Prof. F. Carassa

Director General: J.-M. Luton.

agence spatiale européenne

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

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

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

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

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

Le SIEGE de l'Agence est à Paris.

Les principaux Etablissements de l'Agence sont:

LE CENTRE EUROPEEN DE RECHERCHE ET DE TECHNOLOGIE SPATIALES (ESTEC), Noordwijk, Pays-Bas.

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

ESRIN, Frascati, Italie

Président du Conseil: Prof. F. Carassa

Directeur général: J.-M. Luton.

esa bulletin

no. 73 february 1993

contents/sommaire

Cover: ESA Astronaut Claude Nicollier at work; see pages 55 and 80

Editorial/Circulation Office

ESA Publications Division
PO Box 299, Noordwijk
2200 AG The Netherlands

Publication Manager
Bruce Battrick

Editors
Bruce Battrick
Duc Guyenne
Clare Mattok

Layout
Carel Haakman

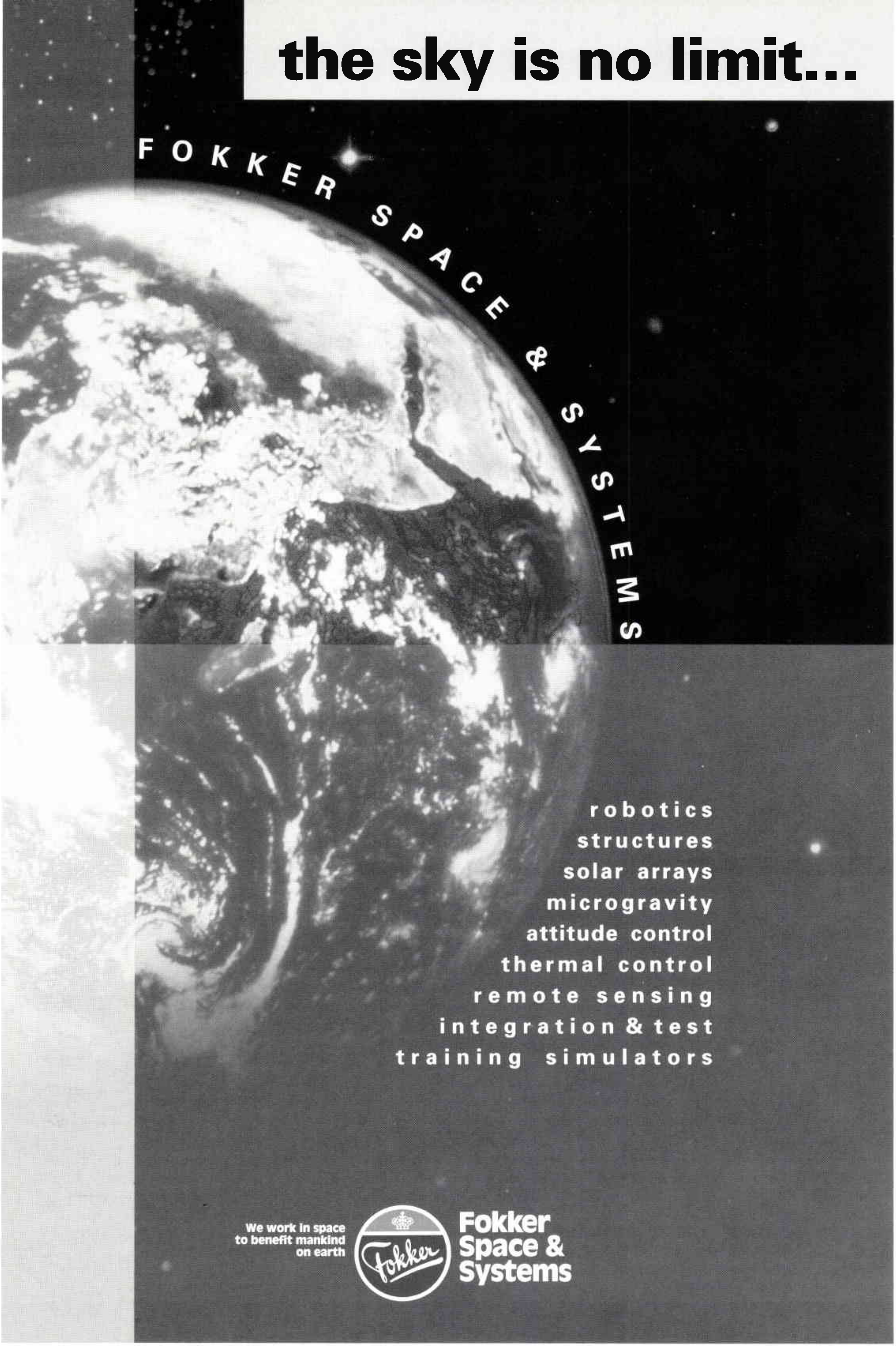
Graphics
Willem Versteeg

Montage
Keith Briddon
Paul Berkhout

Advertising
Brigitte Kaldeich

Printed in The Netherlands
ISSN 0376-4265

european space agency
agence spatiale européenne

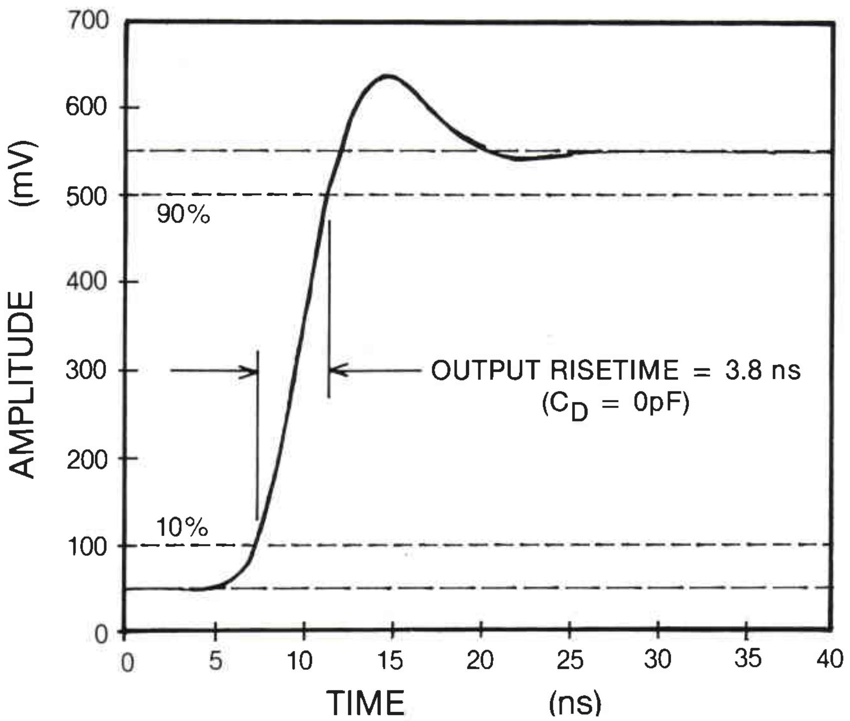


the sky is no limit...
FOKKER SPACE & SYSTEMS
robotics
structures
solar arrays
microgravity
attitude control
thermal control
remote sensing
integration & test
training simulators
We work in space to benefit mankind on earth
Fokker
Fokker Space & Systems

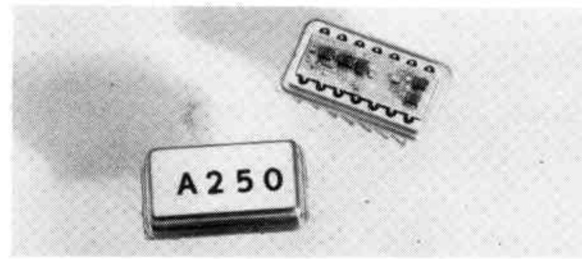
CHARGE SENSITIVE PREAMPLIFIER

A250

RUN SILENT — RUN FAST!!!



A NEW STATE-OF-THE-ART



EXTERNAL FET

FET CAN BE COOLED

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

If you are using: Solid State Detectors, Proportional counters, Photodiodes, PM tubes, CEMS or MCPs and want the best performance, try an AMPTEK CHARGE SENSITIVE PREAMPLIFIER

Send for Complete Catalog

Features:

- Low noise (less than 100 electrons RMS)
- Low power (5 milliwatts)
- Small size (Hybrids)
- High Reliability
- Radiation hardened (as high as 10^7 Rads)
- One year warranty

Applications:

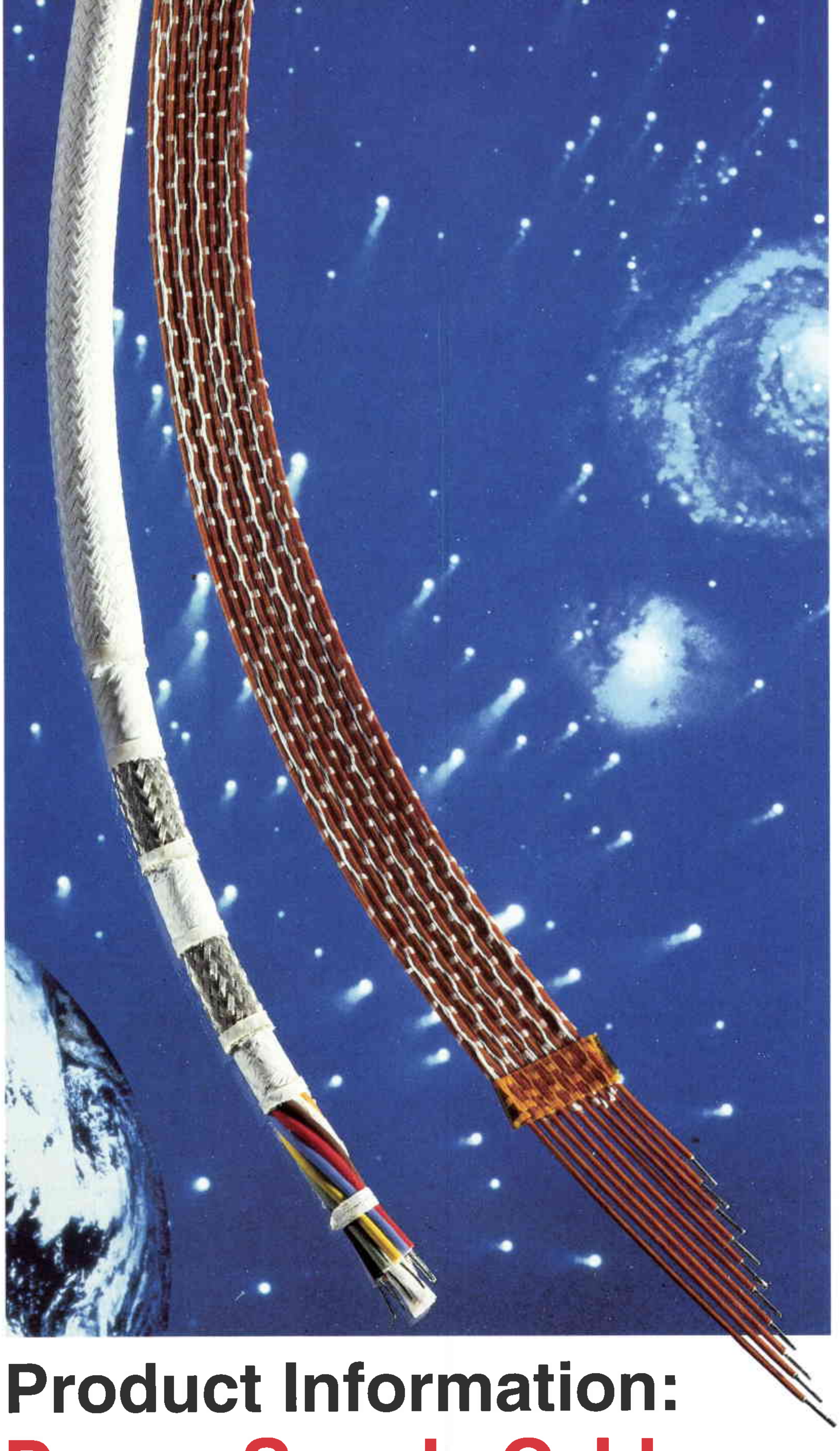
- Aerospace
- Portable Instrumentation
- Nuclear Plant Monitoring
- Imaging
- Research Experiments
- Medical and Nuclear Electronics
- Electro-Optical Systems and others.

AMPTEK INC.

6 DE ANGELO DRIVE, BEDFORD, MA 01730 U.S.A. (617) 275-2242

AUSTRALIA: Austeknis PTY Ltd, Kingswood 2763533; **AUSTRIA:** Item Beratung, Vienna 975958; **BELGIUM:** Landre Intechmij, Aartselaar 8875382; **BRAZIL:** Domex Comercio Exterior Ltda, Sao Jose Dos Campos-SP 234235; **DENMARK:** Eltime, Slangerup 780303; **ENGLAND:** Teknis Ltd., Crowthorne, Berkshire 780022; **FRANCE:** Leversan, Rousset, 42290019; **GERMANY:** Teknis & Co. Sauerlach, 81049543; **HONG KONG:** Idealand Electronics Ltd, Kowloon, 7443516-9; **INDIA:** Bakubhai Ambalai Bombay 6323303; **ISRAEL:** Giveon Agencies ltd, Tel Aviv, 5612171; **ITALY:** C.I.E.R. Roma 856814; **JAPAN:** Jepico, Tokyo 3480623; **KOREA:** Hongwood International, Seoul, 5551010; **NETHERLANDS:** Hollinda B.V. The Hague 512801; **NORWAY:** Ingenior Harald Benestad A/S, Lierskogen 850295; **PAKISTAN:** Fabricon, Karachi 412266; **PHILIPPINES:** QV Philippines Co. Ltd Metro Manila, 8193365.


We view earth differently...
...exercising stewardship of our planet.
With RADARSAT in-orbit by early 1995, Spar will have established a unique capability in global remote sensing.
Advanced Synthetic Aperture Radar technology will provide valuable resource and environmental management information in all weather conditions, day and night.
Another commitment of Spar to "Mission to Planet Earth".
SPAR
Spar Aerospace Limited
Satellite and Communications Systems Division, Quebec, Canada Tel:(514) 457-2150 Fax:(514) 457-2724
ORBITING SOLUTIONS



GORE are specialists in cable constructions for critical transmission systems. GORE special high-performance cables secure the success of space missions through their application-specific design and manufacture.

Contact us early in your concept phase. We will be glad to advise you. We have extremly short turn-arounds for the design, prototyping and manufacture of your special cable requirements.

Main specializations

- Space wires and cables (qualification according to SPACELAB SLP 2110 and ESA/SCC detail specification 3901/007, 008, 009)
- Highly flexible, low-attenuation microwave cable assemblies, applicable up to 40 GHz
- Dielectric waveguides from 26.5 to 110 GHz
- Highly flexible, low-attenuation coaxial cables
- Round and flat conductor ribbon cables
- Data lines
- Round cables
- High voltage wires and cables

Product Information: Power Supply Cable Assemblies for Space Technology

GORE

W.L. GORE & ASSOCIATES GMBH
Nordring 1 · D-8835 Pleinfeld · Germany
Phone: (0 91 44) 6 01 - 0

Hermann-Oberth-Str. 22
D-8011 · Putzbrunn · Germany
Phone: (089)4612 - 507

We're capable of anything.

Highly diversified skills, and an unusually wide product range make Aerospatiale Espace & Défense the only company in the world with complete mastery in all fields of both civil and military space. Industrial architect for Ariane, Aerospatiale has already delivered more than 100 stages of this launch vehicle, and will build some 50 more Ariane 4's before the year 2000. Aerospatiale is also developing the new, and more powerful Ariane 5 launcher, and is leading the industrial team behind Hermes, the European spaceplane. As Europe's major satellite manufacturer, Aerospatiale has already contributed to more than 60 weather, telecommunications, direct TV broadcasting, Earth observation, and scientific satellites. In its capacity as industrial prime contractor for the missile systems of the French nuclear deterrent force, Aerospatiale is also the only European company to design, develop, and manufacture strategic ballistic missiles.

A C H I E V E M E N T   H A S   A   N A M E .

AEROSPATIALE
ESPACE & DEFENSE

PUBLICIS - FCB

Figure 1. The first European Remote-sensing Satellite, ERS-1, shown here flying into sunlight over the Atlantic Ocean, is providing valuable data to help us achieve a better understanding of our environment

A Year of ERS-1 Operations

M. McKay
ERS Mission Operations Manager, European Space Operations Centre (ESOC), Darmstadt, Germany

In just one year, ERS-1 has completed over 5000 orbits of the Earth, equivalent to more than 220 million kilometres, providing a wealth of data for environmental uses and over 200 000 all-weather radar images. Operating ERS-1 in such a way as to ensure that this data is delivered as finished products to users within 3 hours of acquisition and with an availability factor of 98% is a considerable operational challenge.

Introduction

In recent years, public concern about the state of our environment has grown dramatically. Almost 10 years ago, the 13 Member States of the European Space Agency, together with Canada, took a far-reaching decision to begin the construction of Europe's first environmental satellite and the associated complex ground facilities to support it. The objective was to increase both the quantity and quality of scientific data available about our planet and thereby substantially improve our understanding of the environment.

The European Space Operations Centre (ESOC) has conducted the operations for more than 30 spacecraft since it was first established over 25 years ago. Most of the early missions were simpler in design and operations concept, providing a basic service or data to a well-defined user community. In addition, missions were usually 'one off' and had lifetimes of only a few years. The facilities and skills required to control and operate these missions successfully, although challenging with the technology available at the time, are modest in comparison to the demands made on the ground segment by a mission of the size and complexity of the first European Remote-sensing Satellite, ERS-1.

The ERS-1 mission was designed to be an end-to-end system, delivering tailored mission products in near-real-time in response to specific user requests for data. The spacecraft and ground segment designed to achieve this goal were not only sophisticated and ambitious, but required a high of degree coordination and cooperation to make them work.

The satellite instruments use advanced microwave techniques to perform all-weather global monitoring of our environment, providing data not available from existing spacecraft. The large quantity of data and high transmission rates from the spacecraft require advanced data-processing facilities at the ERS-1 ground stations and processing centres. The uses to which the data are put are diverse, and the users themselves are spread throughout the world.

One of the main aims of the ERS mission is to provide a continuous stream of environmental data to the users as quickly as possible. The realisation of the ground facilities to meet these demands posed substantial challenges to the design teams. Their operation was also a challenge that had not been met before.

To achieve the mission aims, a high degree of autonomy on the satellite is required, using multiple onboard computers. This in turn requires a sophisticated mission control system to monitor and control it. The complete ERS-1 system represents the most extensive and complex unmanned mission undertaken to date by the European Space Agency.

The ground-segment concept

The user community is no longer a discrete group whose requirements fall within a single application or field of science. The ERS users are a truly international group of communities actively involved in many diverse aspects of remotely sensing our environment, with many unique needs and uses for the data.

The ERS ground segment has expanded its traditional role to meet these needs by extending its facilities to include complex data processing located at the four main ERS receiving stations. These provide users with tailored mission products within 3 hours of the spacecraft making its measurements. Collaboration with numerous countries outside the ESA Member States has been undertaken in order to collect and process ERS-1 data at other stations around the world, making ERS a genuinely global mission.

The data received at the four main stations are processed into 'Fast-Delivery Products', which are distributed to users within 3 hours of the measurements being taken anywhere around the ERS orbit. The prime station for data reception and processing is at Salmijärvi, near Kiruna in northern Sweden. This station lies within the Arctic Circle, offering contact with the satellite for 11 of the 14 orbits that it makes each day, and is also the prime station for commanding and monitoring the health of ERS-1. ESOC is responsible for the operation of both ERS-1 and the Kiruna station. Canadian stations at Gatineau and Prince Albert receive the data for the remaining three orbits, although Prince Albert has no processing facilities for the one orbit's data that it receives. In addition, stations at Maspalomas in the Canary Islands (E), and Fucino, in Italy, receive data in real time covering the Mediterranean and northern Africa. The data processing at these additional stations is controlled by ESRIN.

Figure 2. ESA's Salmijärvi ground station in northern Sweden, 200 km inside the Arctic Circle, provides the vital command link to ERS-1 and is the main data reception and processing station for the mission

Precision processing and data-archiving facilities have also been set up to offer users a wider and more specialised range of mission products from either recently acquired or archived data. Four centres have been established in Europe to provide these facilities, in Germany, France, Italy and the United Kingdom.

Launch and early orbits

On 17 July 1991, ERS-1 was sitting on top of its Ariane-4 launcher at Kourou, in French Guiana. Teams of engineers monitored every step of the countdown to ensure that everything to do with the launcher was running smoothly and there would be no launch delays. Data from the ERS-1 spacecraft was continuously available through the umbilical connection to the launch tower. The ERS-1 engineering team at the launch pad were carefully monitoring the spacecraft, verifying its health and readiness for launch.

Thousands of kilometres away, almost on the other side of the world, another team was watching also. In the Main Control Room at ESOC sat the ERS-1 Flight Control Team. They too were constantly monitoring the ERS-1 telemetry data, being relayed over thousands of kilometres, and were performing final checks to verify that everything was 'go' for launch. Displays of spacecraft parameters were scanned for any subtle changes that could have indicated a problem. Final tests with the worldwide network of ground stations that would track ERS-1, collect its telemetry, and provide the Flight Control Team with the ability to command ERS-1, confirmed that they were all ready to support the launch. Shortly before the opening of the ERS-1 launch window, a final status report from each of the Mission Control Centre launch teams confirmed their readiness for launch. All systems at ESOC were reported to Kourou as 'green' for launch.

At 01.46 UT, as the launch window opened, the Ariane-4 vehicle slowly lifted from its pad and climbed gracefully away from the launch tower – the ERS-1 mission had begun. After the many months of training and simulations, this time the operations activities were the real thing.

The Mission Control Centre sprang to life as command sequences were recomputed with the real lift-off time. Spacecraft parameters being relayed from the tracking station at Kourou were scrutinised by the Flight Control Team for any deviations. As the Ariane vehicle headed north, the Flight Dynamics Team at ESOC recomputed its trajectory,

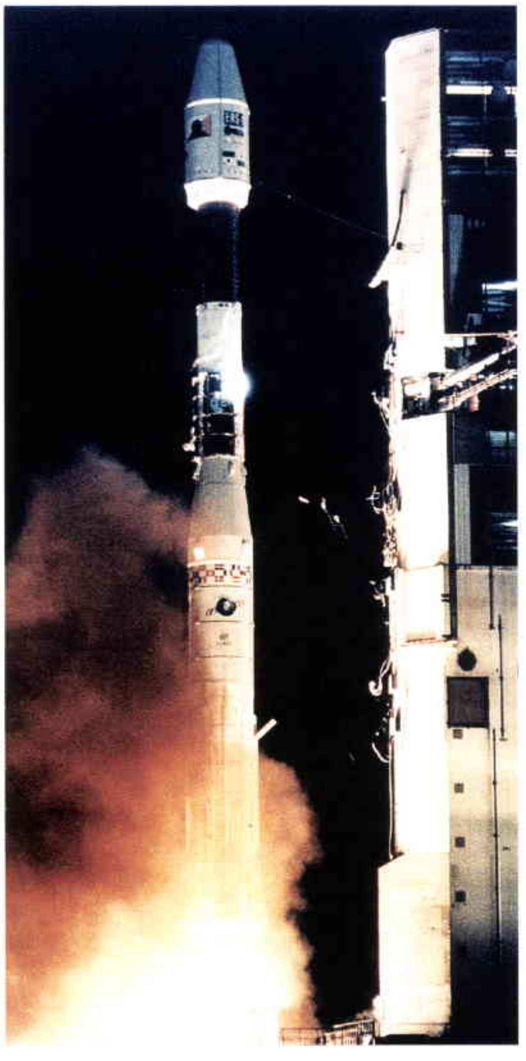


Figure 3. An Ariane-4 lifts off from Kourou, in French Guiana, on 17 July 1991 carrying ERS-1

ready to send new tracking data to the ground-station network if the launcher should deviate from its expected course.

19 min later, some 780 km above the Atlantic Ocean and just east of the Canadian coast, Ariane completed its task successfully and injected its valuable 2.3 ton passenger, ERS-1, into the prescribed orbit. The onboard attitude-acquisition and deployment sequence started automatically, bringing the spacecraft's attitude under control, unfolding the antennas and releasing its mechanisms. This sequence continued until a problem with the earth sensors was detected, forcing a reconfiguration to the backup sensors and bringing it to a halt.

Commands were sent from the Mission Control Centre to continue the deployment of the antennas, but further problems were encountered when the Scatterometer's forward-pointing antenna failed to deploy. Again, the Flight Control Team followed well-rehearsed recovery procedures and successfully deployed the antenna using the backup system. The deployment was continued by manually commanding the spacecraft from the Mission Control Centre until all antennas and the solar panels were deployed. Only the deployment of a backup antenna could not be definitively confirmed until later, as the microswitch used to verify its final position had failed.

Several orbits later, the spacecraft fine-pointing mode did not converge correctly and an attitude re-acquisition occurred when the reaction wheels, used to maintain the spacecraft's attitude, saturated. The problem was quickly identified, with the help of the industrial support team available at ESOC, as being due to use of an incorrect sign in the onboard software responsible for activating the magnetorquers. This sign error was corrected by commanding a change to be made to the onboard computer code.

On further investigation, it was found that the earth sensors were performing too well and had exhibited so little noise that the onboard computer thought they were not working correctly. The sensors were therefore manually reconfigured back to the prime units again.

Despite the initial problems, the ERS-1 Mission Control Centre had successfully completed the deployment of all antennas and mechanisms, with all the prime subsystems functioning correctly and the spacecraft attitude converged in the operational yaw steering mode. The solar array was also estimated to be producing 2500 W, which was more than expected, and providing ample power for full payload operations.

Figure 4. The Mission Control Team manually commanding the deployment of the ERS-1 Scatterometer's aft antenna from the Main Control Room in ESOC

The commissioning phase

The first orbit-control manoeuvres to trim the ERS-1 orbit and start the drift towards the commissioning-phase orbit were performed 3 days after launch. During this drifting phase, the payload instruments were switched on one by one, starting with the tape recorders and data-transmission system, and tested for correct functioning and operation. As each instrument was verified, the Mission Management and Planning Office at ESOC began scheduling its operation, providing commands to the mission-control computers for uplinking to ERS-1.

Figure 5. Spacecraft controllers and Kiruna station controllers operate the mission 24 hours per day, seven days a week from the ERS-1 Dedicated Control Room at ESOC

At the same time, control of the Kiruna ground station and data-processing facility was assumed by the Kiruna Operations Team at ESOC, supported by the staff at the station. Just 10 days after launch, the first Synthetic Aperture Radar (SAR) image was taken over Spitzbergen (N), and successfully received and processed at Kiruna. This one image confirmed the successful operation of many of ERS's major system elements and its ability to image sea-surface features, sea ice, land features and glaciers.

As the instrument switch-on sequence was concluded, the station network used for commanding and telemetry monitoring during launch was gradually reduced to only two ground stations: the nominal Kiruna station for routine operations, and the Villafranca station outside Madrid (E) for back-up telemetry and telecommanding. In contrast, the data-reception-station network for receiving the data from ERS-1's instruments started to grow. Stations were added to the network, providing more global acquisition of ERS-1 image data, until it was possible to receive imagery of almost every part of the world.

By the end of July, the mission planning for all the spacecraft and Kiruna Station operations and processing was being performed by the Mission Management and Planning Office at ESOC.

The commissioning phase continued for the next 4 months, with maximum priority given to engineering validation of the complete ERS-1 end-to-end system and geophysical validation of the data being collected.

Routine operations

With the initial switch-on and validation process completed, the commissioning operations assumed a more routine pattern. The Industrial Support and ESTEC Project Teams, pleased with the spacecraft's operation, returned home. The Mission Control Team moved from the Main Control Room at ESOC into the nearby ERS-1 Dedicated Control Room, and the spacecraft and Kiruna station operations for the commissioning phase became more routine.

With the near-circular, Sun-synchronous orbit of ERS inclined at 98° to the equator, an ERS-1 'day' lasts only 100 min. It experiences 35 min of 'night' as it flies over the dark side of the Earth and is itself in the Earth's shadow; the remaining 65 min in sunlight are ERS-1's daytime.

As the spacecraft orbits about 780 km above the Earth's surface, it travels with a ground speed of 7 km/s, taking 25 min to travel from the North Pole to the Equator. Seen from the ground station, the average time taken for ERS-1 to go from horizon to horizon, and therefore the time available for commanding and data collection, is only 10 min. ERS-1 is therefore out of ground contact for 90% of each orbit for any given ground station.

The spacecraft's Synthetic Aperture Radar (SAR) produces image data at a rate of 100 million bits per second, or the equivalent of 5600 pages of text per second. This data can only be transmitted directly when in sight of a ground station. The one million bits per second of other scientific data from ERS-1 are recorded by onboard tape recorders, and played back when in ground contact.

User requests for products are received and processed by the Central User Service at ESRIN in Frascati (I). Since late September, ESRIN has been passing user requests for SAR image operation and images or special products to be generated at the Kiruna station, to the Mission Management and Planning Office at ESOC. It is here that the mission planning for the ERS-1 spacecraft and Kiruna station operations is performed.

Coherent and optimised schedules for the spacecraft, data recording and playback over the ERS-1 station network, and all the Kiruna station operations schedules are produced for up to one month in advance. These plans are sent to ESRIN, which notifies users of the planned operations. Each day, the schedules for the next 24 hours are transferred to the mission-control computers for uplinking to the spacecraft or transmission to the Kiruna station.

ESOC's Flight Dynamics Services recompute the ERS-1 orbit every day, providing the Flight Control Team with up-to-date orbit predictions and command sequences for orbit and attitude control. These latest orbit predictions are used to recompute accurate times for the spacecraft and Kiruna station schedules produced by the ERS Mission Management and Planning Office. Commands are sent to the spacecraft to programme up to 24 hours of operations in advance, and the schedules covering the next 24 h of data acquisition and processing are then transmitted to the Kiruna station.

On-board autonomy

These mission characteristics, together with the complexity of ERS-1, require a high degree of onboard autonomy that can control spacecraft operation, record events that happen around the orbit, react logically when detecting problems onboard the spacecraft, and report them at the next contact with Kiruna. For this reason, virtually all of the spacecraft and instrument functions are controlled by computer programs running in the 9 active computers of the 17 onboard. This has also had the major advantage of being able to correct problems encountered after launch, like those during the early-orbit phase. The programs can also be adjusted to provide more detailed diagnostic data when investigating onboard problems, or to correct and change data-collection algorithms in the instruments, improving the quality of the mission products. On a spacecraft as complex as ERS-1, such a degree of flexibility is essential.

ESOC is responsible for the onboard software maintenance for these computers, in conjunction with the manufacturers. The expertise and skill of the operations team in understanding these onboard programs, as well as in being able to manipulate and change the computer code, is one of the major factors contributing to continuing mission success.

The invaluable spacecraft simulator

For training and system-testing purposes, ESOC developed a computer simulation of the ERS-1 spacecraft. As accurate simulation was essential, a new approach was adopted for simulating such a complex spacecraft. Part of the simulator was built to behave just like the main computer aboard ERS-1. The program code from this main computer was sent to ESOC and loaded into the simulator

Figure 6. Mission planners prepare the ERS mission operations in the Mission Management and Planning Office at ESOC, to meet user needs

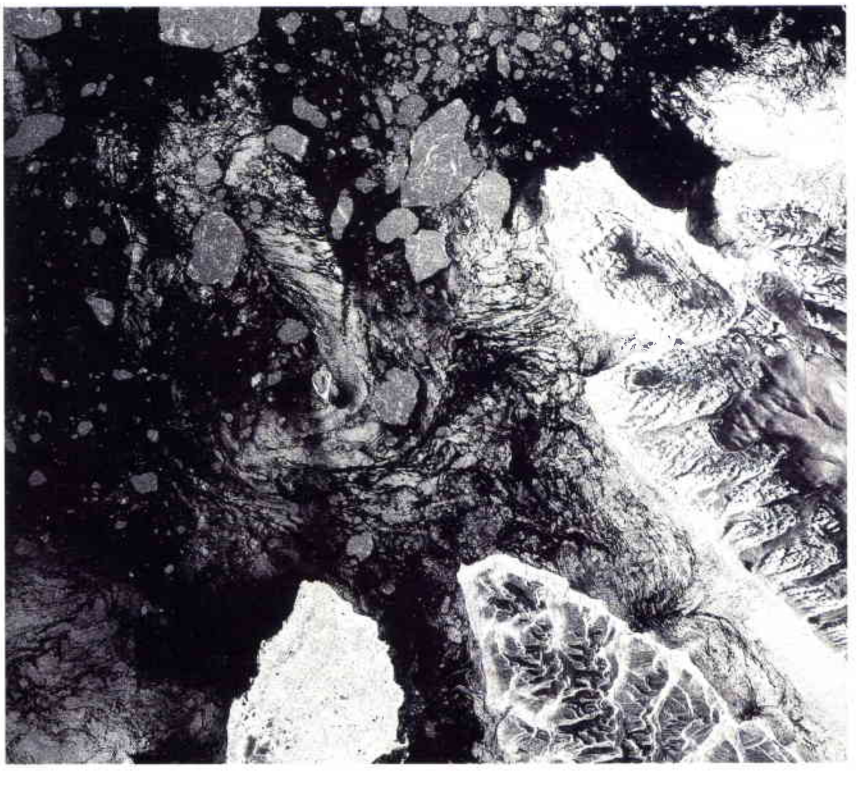


Figure 7. Spitzbergen – the first ERS-1 image, received and processed at the Salmijärvi Station, in Kiruna. Sea-surface features, sea ice, land features and glaciers are clearly visible

Figure 8. An image of part of the South American Rain Forest, showing areas of deforestation in red, indicates the extent of the damage to the world's ecological balance

and started running. The results were exceptional: not only was the simulation accurate, but it indicated potential operational difficulties that would not have been evident had a traditional approach been taken. As most of the spacecraft functions are performed by this program, it was also possible to test changes to the code and verify their correct functioning before uplinking them to the spacecraft.

This type of simulation has been an invaluable tool for training the operations teams in handling possible emergencies, for testing operations procedures, and for testing the mission-control system itself prior to satellite launch. The accuracy of the simulation has increased confidence in satellite operational changes, as they are tested on the simulator before being approved. It has also shown the necessity for accurate simulation in spacecraft operations.

Mission achievements

Despite the ERS-1 mission being pre-operational in nature, the high and continued availability of the system and its products is more characteristic of a fully operational mission. 98% of the user requests for products from the Kiruna station have been met, with 98% of these products being available to the users within 3 hours of data acquisition. Over 15 000 images have been processed by the Kiruna station and disseminated to users in the first year of operations. Data for almost 200 000 further images have been acquired at Kiruna and other stations, and are available to users.

The ERS Mission Management and Planning Office at ESOC has successfully planned the ERS-1 mission from the first instrument switch-on after launch. During the first year of operations, ESOC has changed ERS-1's orbit on three separate occasions to meet the needs of the 'Commissioning Phase', the 'First Ice Phase' and finally the 'Multi-Disciplinary Phase'. In addition, two 'roll/tilt' campaigns were carried out in December 1991 and April 1992, respectively. These involved rolling the spacecraft body through an angle of 10° so that ERS's instruments viewed the Earth at a different angle. A total of 46 such roll/tilt operations were successfully performed. Fine-control manoeuvres to maintain the orbit within its tight specification have been performed once every two to three weeks, on average.

After a year in orbit, ERS-1 has completed over 5000 orbits of the Earth, equivalent to travelling over 220 million kilometres. Of the 317 kg of fuel available onboard the satellite at launch, 288 kg remain, giving an average fuel consumption of just under 8 million kilometres per kilogramme!

Conclusion

During ERS-1's first year in orbit, ESOC has successfully performed all of the mission operations entrusted to it, from mission-planning user requests for sensing the environment, processing the data, and making it available to the users. Seen from an overall ERS-1 System viewpoint, the 'pre-operational mission' objectives that were set have been continually met or exceeded over the first year of operation.

The success of such a sophisticated and ambitious mission as ERS-1, with its widely distributed ground segment and user communities, has been fostered by the close cooperation between the many highly skilled people, in many different institutes and countries, who have been involved in the mission. With this success and cooperation, the European Earth Observation Programme has a good foundation on which to build its future in observing and understanding our environment.

Hurricane Andrew Monitored Using Meteosat

B. Mason
Meteosat Exploitation Project, European Space Operations Centre (ESOC), Darmstadt, Germany

Since hurricanes form over the sea where conventional ground-based meteorological observations are very limited, satellite imagery often provides the information required to monitor the development and progress of a hurricane.

ESA's weather monitoring satellite, Meteosat-3, began operating at 50°W in 1991 to provide greater coverage of the Atlantic Ocean from a more westerly location. In August 1992, it proved to be particularly advantageous during the Atlantic hurricane season: imagery gathered by Meteosat-3 was used to determine very precisely the track that Hurricane Andrew, the most devastating hurricane to strike the mainland USA for many decades, would take. It allowed an early warning to be issued and thereby allowed the damage caused by Andrew to be minimised.

Hurricanes and their characteristics

Tropical storms are well-known occurrences in several geographical areas of the Earth but in Europe, where we generally do not experience the violent weather that such storms can bring, we are probably most familiar with those known as hurricanes. This is the name given to tropical storms that occur in the southern regions of the North Atlantic Ocean, the Caribbean Sea, the Gulf of Mexico and the eastern Pacific Ocean.

Storms that exhibit the same basic characteristics but occur in other parts of the world are known by different names: as typhoons if they occur in the northern Pacific Ocean and China Seas, and as cyclones if they occur in the northern Indian Ocean.

The Atlantic hurricane season generally begins in mid-July and continues until mid-October but tropical storms can happen outside this period. The number of hurricanes that occur each year varies, as does the intensity of the storm and the devastation that it brings. On average, five to six Atlantic tropical storms achieve hurricane status each year. Hurricanes of potentially the most violent and destructive nature receive extensive media coverage while other storms receive little or no attention. However, from the meteorologist's viewpoint, each hurricane is of interest and provides more information about this potentially very destructive weather phenomenon.

Hurricanes are a feature of lower latitudes. They always develop over the open ocean but generally not within the 5° latitude band on either side of the equator. A major criterion for their development is a sea surface temperature of about 27°C or higher. The storms that are experienced in the Caribbean Sea, the Gulf of Mexico and the southern states of the USA often originate near the west coast of Africa, initially developing in weak troughs or easterly waves. In these convergence zones, large cumulonimbus clouds can form and, if conditions are favourable, the atmospheric pressure falls rapidly resulting in the creation of a tropical storm with organised patterns of convective clouds and cyclonic motion. Initially, the storm may not bear all the typical characteristics of a hurricane but as it travels westward, collecting moisture and being heated by the warm sea surface below, it may develop into a full-scale hurricane. At this stage, it is typified by an 'eye' at the centre of the storm, which usually consists of light winds and broken cloud and is generally about 20 to 30 km in diameter (in its mature stage, the hurricane has an overall diameter of 300 km or more). The eye is bounded by a wall of cloud, and the strongest winds and heaviest rainfall usually occur in the region immediately outside the eye.

The hurricane follows a track that is often erratic and depends, amongst other factors, on the surrounding meteorological environment. While the hurricane initially moves westward, it usually turns to the north or northwest eventually. If it turns northward at an early stage, it often becomes enmeshed in the polar weather front and continues eastward as a normal frontal depression, which may eventually influence the weather in Europe. With hurricanes that originate around West Africa, the point at which they change direction is extremely important: an early turn to the north may prevent the landfall of the hurricane and the disastrous consequences thereof.

Monitoring hurricanes

In the United States, the National Hurricane Centre (NHC), based in Coral Gables, Florida, holds the major responsibility for monitoring the progress of hurricanes. The process involves the detection, tracking, analysis, and prediction of hurricanes and, finally, the issuing of a hurricane warning. Given the violent nature of these storms, it is important to track their progress and development as accurately as possible and to provide a timely warning to the areas likely to experience the full wrath of the storm. This can minimise loss of life and damage to property, which in the worst case can amount to many billions of dollars.

Since hurricanes form over the sea where conventional ground-based meteorological observations are very limited or non-existent, observations gathered by satellite or aircraft provide the most important information. Observations collected by specially-equipped aircraft can provide great details of the structure of the hurricane and very accurate determinations of the location of its centre. (During Hurricane Gilbert in September 1988, there were 70 flights into the centre of the hurricane over a seven-day period.) However, such flights are costly, particularly if the hurricane is located well out to sea. Therefore, geostationary satellites, with their capability of capturing images of the Earth every half hour, can contribute significantly to observing a hurricane's progress and development.

Over the years, the NHC and other laboratories have developed many techniques to assist in defining a hurricane's most likely track and the severity of the storm. Many of these techniques involve the use of satellite imagery such as the Meteosat weather satellite, provides. Imagery from the three spectral channels (visible, infrared and water vapour) provides information that is useful for locating the storm, predicting its movement, determining wind speeds and estimating rainfall amounts. The precise location of the eye is extremely important and, although the visible channel usually provides the best information for locating the eye, the infrared channel imagery is essential during the hours of local darkness. While nominally the geostationary meteorological satellites provide half-hourly imagery, the Geostationary Operational Environmental Satellites (GOES), operated by the National Oceanographic and Atmospheric Administration (NOAA), are often used in a rapid scan mode, i.e. repeated imaging of the immediate area of the hurricane is carried out, to obtain even more frequent observations. The cloud structure observations in all spectral channels contribute to knowledge about the intensity of the storm, and imagery from the water vapour channel can provide information on meteorological features likely to constrain or accelerate the hurricane's development.

Research has shown that the movement of the centre of a hurricane is strongly correlated to a weighted, deep-layer mean wind (DLM) derived from winds at levels between 850 hPa and 200 hPa. Satellite imagery provides an important input to the calculation of the DLM. Using a succession of images from each of the different spectral channels, wind speed and direction in the vicinity of the storm can be obtained by tracking cloud features and water vapour structures at different levels. Rainfall from hurricanes can be intense over very short periods of time, 300 mm or more locally. Using satellite imagery, especially that from the infrared channel, the coldest, highest cloud tops, which are likely to produce the most significant rainfall, can be identified. Thus, together with conventional numerical weather forecasts and aircraft observations, satellites play an important part in providing a warning to those communities likely to be affected by the storm.

Meteosat's observations of hurricanes

Since many Atlantic hurricanes originate in the tropical latitudes of the North Atlantic Ocean, Meteosat has been able to observe a number of hurricanes during its years in orbit. The following figures illustrate hurricanes observed by Meteosat in recent years.

Figure 1 shows Hurricane Helene as observed by Meteosat-3 while operating at 0° longitude. This image of Helene, taken at 1200 UTC on 23 September 1988, coincides with the time of estimated maximum intensity. Helene originated in a tropical wave on the eastern side of the Atlantic and achieved hurricane status one week later, on 21 September. It remained over the Atlantic Ocean throughout its life, starting to turn northward on the day this image was taken. Helene's greatest claim to fame was that it maintained hurricane status for approximately nine days, the longest lived hurricane of the 1988 season.

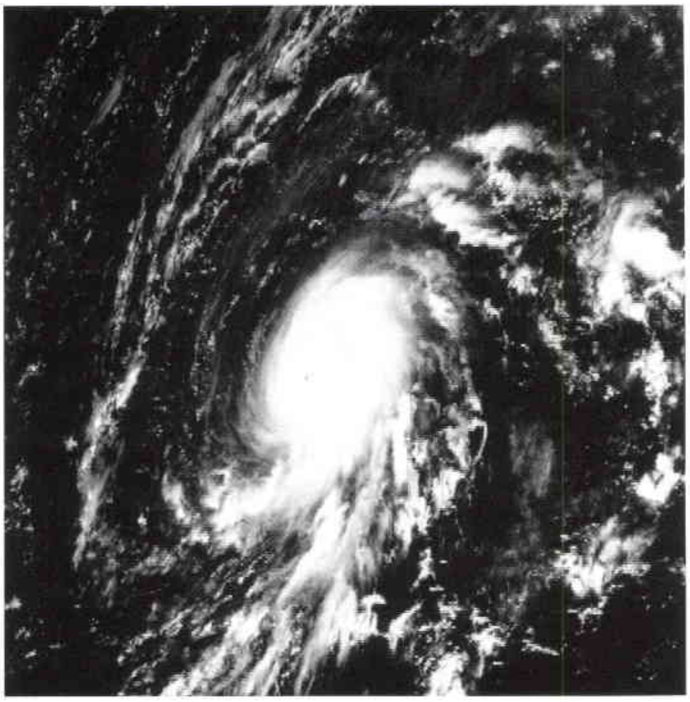


Figure 1. Visible image of Hurricane Helene, taken by Meteosat-3 operating from its nominal location of 0° longitude.

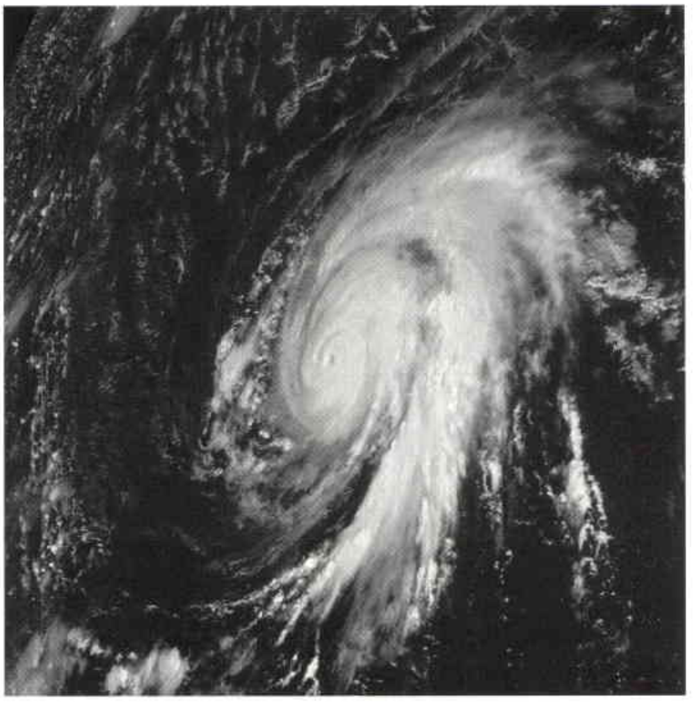


Figure 2. Visible image of Hurricane Gabrielle, taken by Meteosat-4. Gabrielle was a very large hurricane with an eye diameter of more than 80 m when most mature.

Hurricane Gabrielle, shown in Figure 2, fortunately never made a landfall since it was an extremely large hurricane with an eye diameter of over 80 km in its most mature stage. Winds of hurricane force extended a long way from its centre and these generated large swells all along the North American coastline. The image, taken by Meteosat-4 at 1200 UTC on 3 September 1989, shows Gabrielle near 17°N, 49°W just before it started to take a more northerly track, thus never reaching the Caribbean and mainland USA.

Hurricane Hugo, shown in Figure 3, appeared shortly after Gabrielle and caused considerable damage in the northern Caribbean and in parts of North and South Carolina. At that time, it was considered to be the most costly hurricane ever, with damage costs estimated at US$10 billion. The image, as viewed by Meteosat-4 at 1200 UTC on 16 September 1989, also shows tropical storm Iris in the early stage of development, to the east of Hugo. Iris failed to achieve hurricane status.

Figure 4 shows Hurricane Gustav and the early stages of Tropical Storm Hortense, as seen by Meteosat-4 at 1200 UTC on 27 August 1990. Although there was an above-average number of hurricanes in 1990 (eight compared with the 50-year average of 5.6), none was very intense. Gustav turned north when it was several hundred kilometres to the east of the Caribbean and Hortense never surpassed its tropical storm status.

Meteosat's observations of Hurricane Andrew

Meteosat captured all of the images described above from its nominal location at 0° longitude. Another Meteosat mission, named the Atlantic Data Coverage (ADC) mission, began on 1 August 1991. Meteosat-3 began operations at 50°W to provide greater coverage of the Atlantic Ocean from a more westerly location. This satellite not only provides European weather services with enhanced information on mid-latitude storms, but also assists NOAA in its observations of the western Atlantic Ocean. This can be particularly advantageous during the annual hurricane season since, at present, NOAA geostationary meteorological operations are confined to one satellite, GOES-7 which is located at 112°W from where it is unable to view the early stages of hurricane development in the Atlantic Ocean. This situation will continue until early 1994, when the first of a new generation of GOES is due to be launched. Therefore, provisions are currently being made to operate Meteosat-3 at a position that is even more westerly (up to 100°W) through a cooperation agreement between ESA, NOAA and Eumetsat, the European organisation for meteorological satellites. This operation will provide even better coverage of the western Atlantic Ocean and the Americas. It is

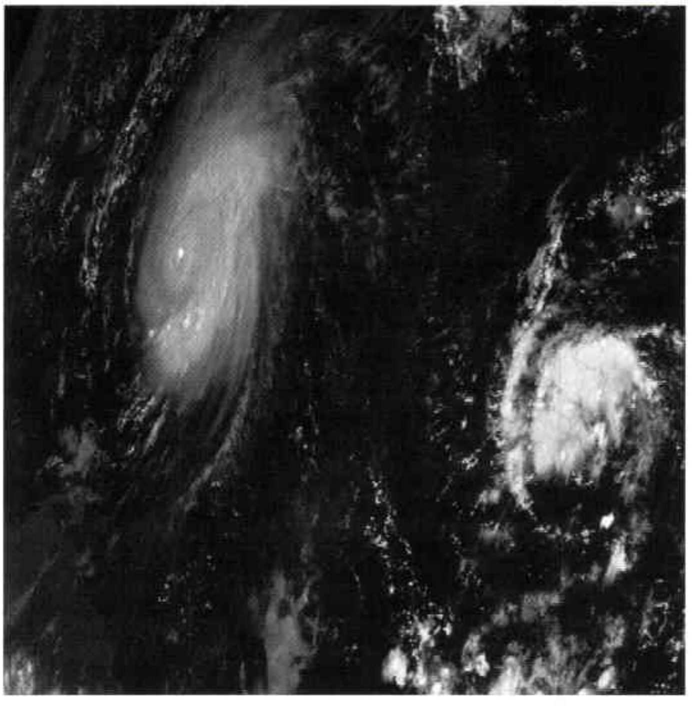


Figure 3. Hurricane Hugo (left) and the early development of Tropical Storm Iris (right) as seen by Meteosat-4. The coast of South America is in the bottom left.

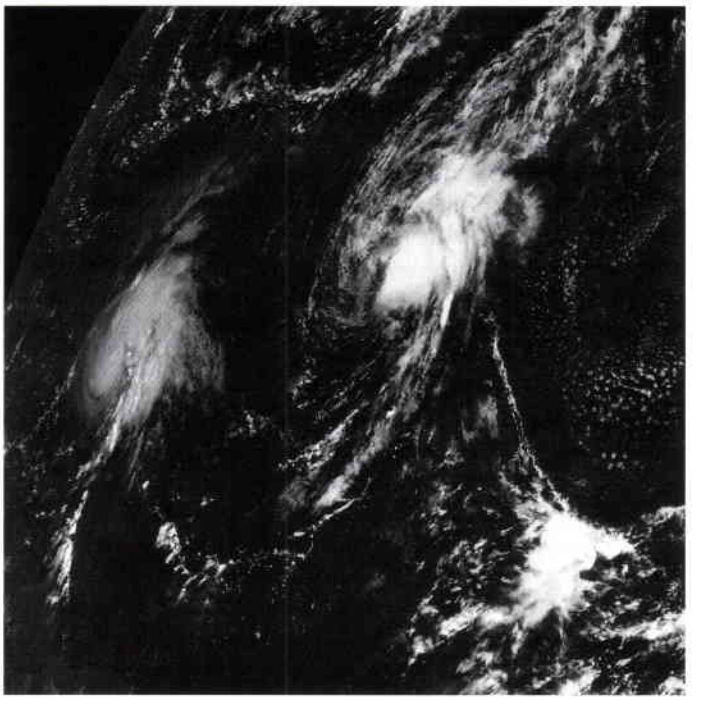


Figure 4. Visible image of Hurricane Gustav (left), and Tropical Storm Hortense (right) in the development stage, as seen by Meteosat-4.

scheduled to begin in early 1993 and will be known as the extended ADC (XADC) mission.

The operation of Meteosat-3 at 50°W, which began in August 1991, was an immediate success. Its importance was further emphasised in August 1992 when the first hurricane of the season, Hurricane Andrew, began approaching the Caribbean islands and the southern USA.

Andrew can be traced back to a disturbance off the coast of West Africa which was first noted in imagery from Meteosat-4 on 12 August. However, the first true indications of a developing tropical storm were observed in Meteosat-3 imagery on 15 August; the cloud formation situated to the south of the Cape Verde Islands, began to become organised with spiral cloud formations emanating from its centre. The NHC officially designated it as a tropical storm on 17 August at 0300 UTC. The depression continued to move northwestward and, later that day at 1500 UTC, when the storm was near 13°N, 43°W, the NHC classified it as Tropical Storm Andrew based on visible and infrared imagery from Meteosat-3 (Fig. 5). The NHC continued to monitor Andrew's progress using Meteosat-3 imagery, and reconnaissance aircraft from the United States Air Force Reserve began flights into the storm on 19 August. By 1500 UTC on 21 August, the storm had already developed the familiar eye (Fig. 6). At 0900 UTC on 22 August, shortly after Andrew entered GOES-7's useable field of view (Andrew was at approximately 26°N, 67.5°W), the NHC officially upgraded it to hurricane status.

It was apparent that Andrew could pose a serious threat to life and property in the Caribbean and the southern states of the USA. However, Meteosat-3 was scheduled to be taken out of service for up to 24 hours for maintenance work on 24 August, the day that Andrew was expected to make landfall in Florida. The Meteosat mission control centre at ESOC agreed to a request from the Satellite Services Division of the NOAA National Environmental Satellite, Data and Information Service (NOAA/NESDIS) to delay the Meteosat-3 outage by 48 hours.

The forecast proved to be very accurate: after causing serious damage to some of the Bahamian islands on 23 August, Andrew made landfall on the Florida coastline at approximately 0830 UTC on 24 August. Andrew's progress was followed on the meteorological image display consoles at ESOC. It was observed that after crossing the Florida peninsula, immediately south of Miami, Andrew moved into the Gulf of Mexico and started to track in a more northwesterly direction (Fig. 7). The hurricane then posed a serious threat to the Gulf states

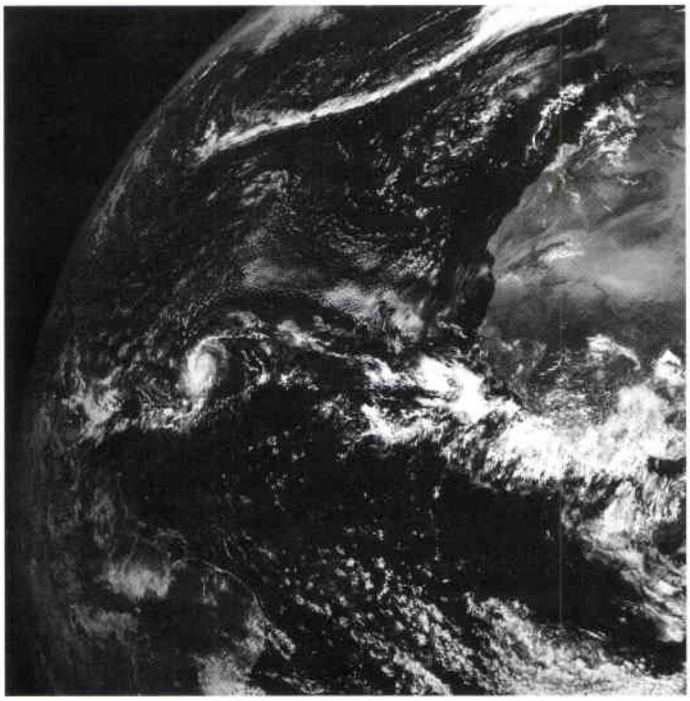


Figure 5. Andrew at the time that it was classified as a tropical storm on 17 August 1992, taken by Meteosat-3. The centre of the storm is located near 13°N, 43°W.

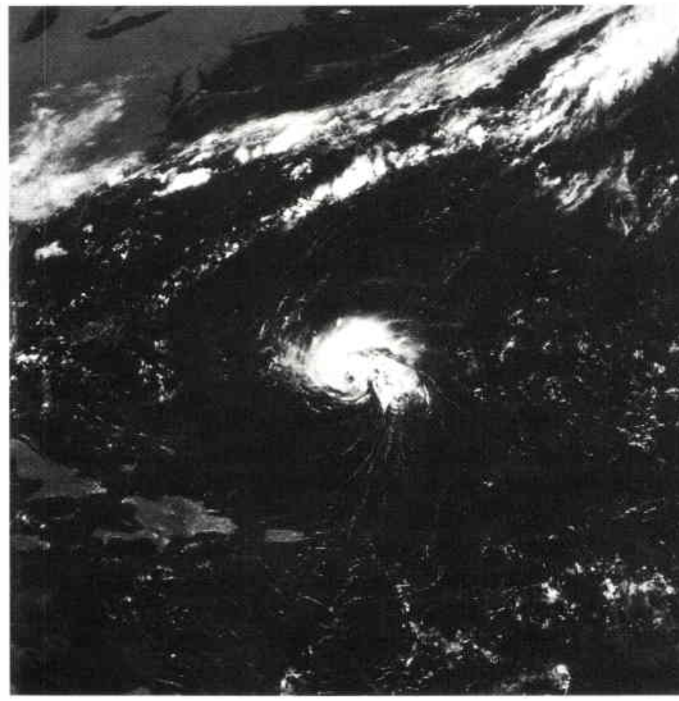


Figure 6. Visible image of Hurricane Andrew, taken by Meteosat-3 from its location at 50°W at 1500 UTC on 21 August 1992. The Caribbean islands are to the lower left of Andrew. Although not officially classified as a hurricane until 18 hours later, the storm shows the familiar eye associated with hurricanes.

of the USA, and a further delay to the Meteosat-3 outage was agreed upon. Eventually Andrew was observed to cross the Louisiana coast to the west of New Orleans at about 0730 UTC on 26 August. In Figure 8, a series of combined visible and infrared images show Andrew as it proceeded from the area of the Bahamas, across Florida into the Gulf of Mexico and finally into Louisiana. The hurricane attained sustained winds of at least 65 ms^{-1} and a minimum central pressure of 922 hPa on 23 August and, based on the Saffir-Simpson scale of 1 to 5 used to categorise hurricanes, Andrew was considered to be a strong Category 4 hurricane. Continuous surface wind speeds of 60 ms^{-1} were still being recorded as Andrew crossed the Louisiana coastline.

Hurricane Andrew appears to have been the most severe hurricane to affect the mainland USA for at least fifty years and possibly this century. The most serious damage was inflicted on the town of Homestead to the south of Miami, and the projected costs of damage to property appear to be the highest ever, possibly in the region of US$20 to US$30 billion, surpassing those of Hurricane Hugo in September 1989. The timely warning of the approach of Andrew was initially primarily due to the availability of imagery from Meteosat-3 and Meteosat-4. While much of the devastation caused by the storm could not be prevented, the precise early warning

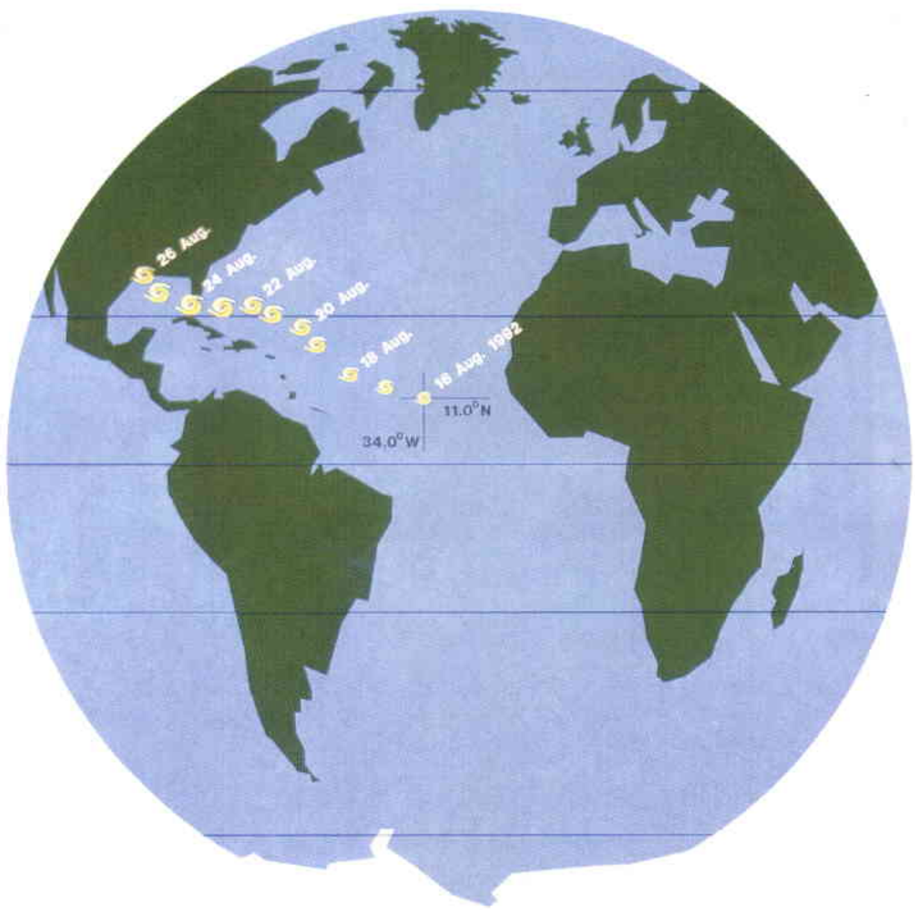
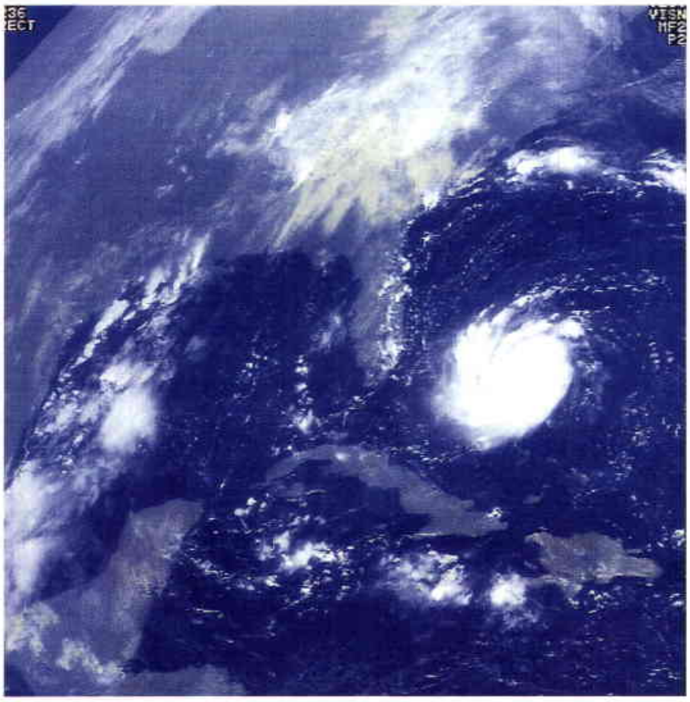
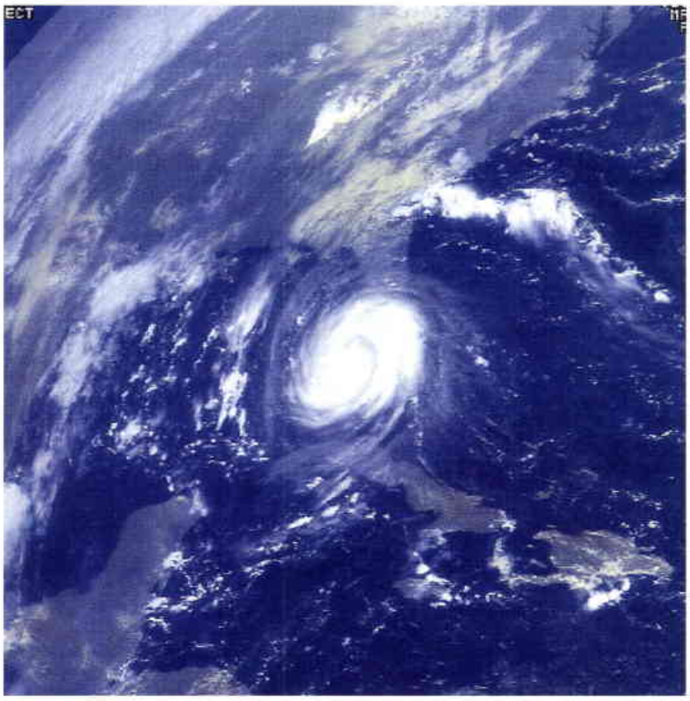


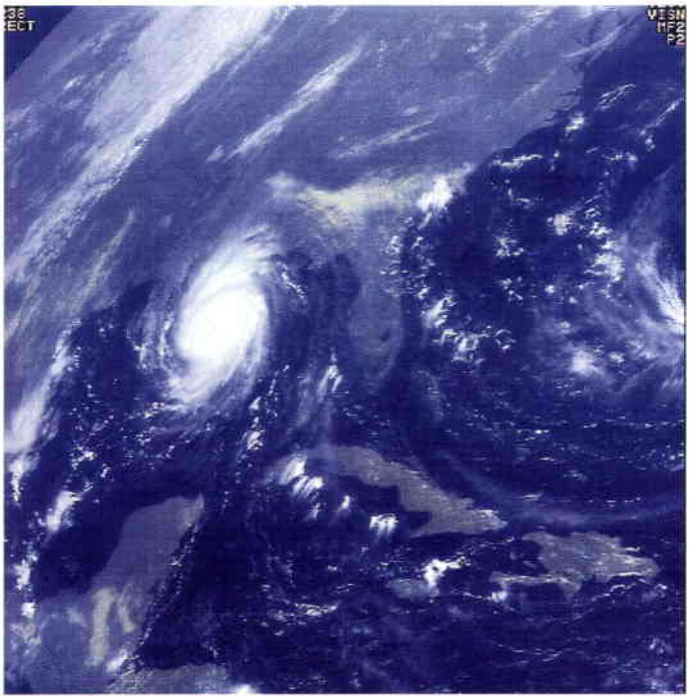
Figure 7. Approximate track of the tropical storm that eventually developed into Hurricane Andrew. The positions given are based on visible imagery from Meteosat-3, taken at 1500 UTC on each day between 16 and 26 August 1992.



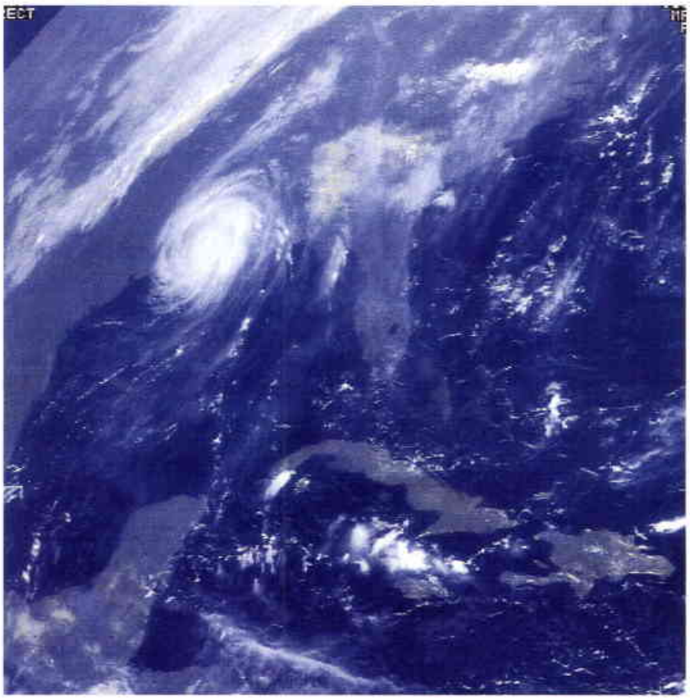
A. On 23 August, in the vicinity of the Bahamas



B. On 24 August, shortly after crossing the Florida peninsula



C. On 25 August, in the Gulf of Mexico



D. On 26 August, after passing over the Louisiana coastline near Morgan City.

Figure 8. Series of combined infrared and visible false colour images showing Hurricane Andrew's progress, taken by Meteosat-3 at 50°W

provided by the NHC allowed some preparations to be made — removal of civil and military aircraft from the area and evacuation of many of the population, the latter resulting in little loss of life. Without the availability of satellite imagery to provide the constant view of the hurricane's progress, the casualty rate could have been more severe.

Co-operation between operators is important to the success of geostationary meteorological satellite programmes, a fact that was first emphasised during the three-year period that began in August 1985, when NOAA was able to make their GOES-4 satellite available to ESA and the European Weather Services for operating the Meteosat Data Collection System. This spirit of co-operation has now been further underlined during the life of Andrew.

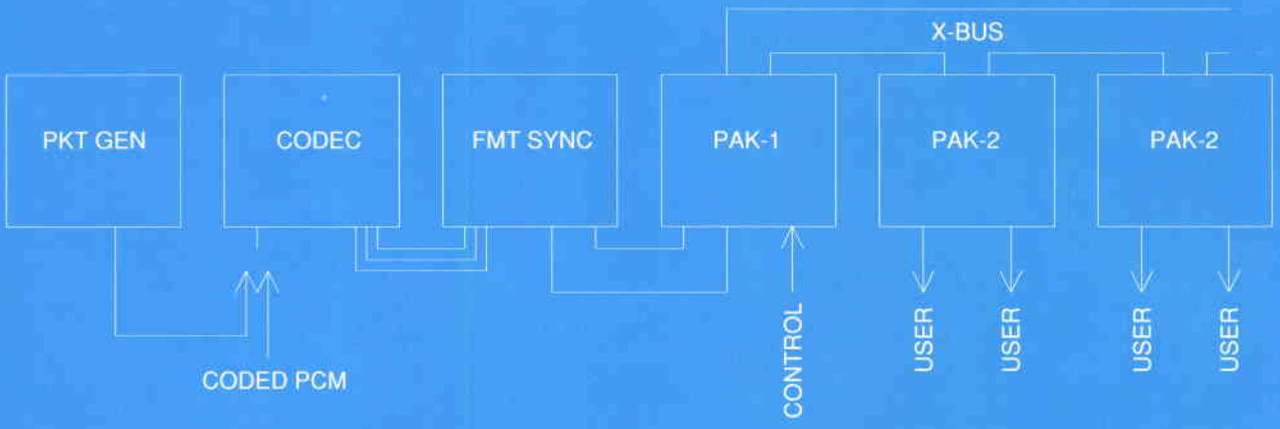
Packet Telemetry Extraction System

Also available for both VME and PC/AT Systems

The Packet Telemetry Extraction system is a self-contained data decommutation system which contains many original features and performance advantages over its contemporaries. Its unique architecture gives a powerful but extremely flexible system which is readily configurable to different Users' demands and easy to use and maintain.

This multi-processor multi-function system has been designed to provide not only modular growth when required but also not limit the User to specific functions and facilities. With the Packet Telemetry Extraction system the User can meet his current and future requirements exactly. Even more importantly, the flexibility of the Packet Telemetry Extraction system means that increasing throughput requirements can be dealt with without changes in operating system or applications software and without the loss of any system performance during expansion. The bus structure used also allows standby processing and multi-stream data processing to be implemented easily, and with the unique communications link, several units may be linked together giving increased flexibility and processing power.

The Packet Telemetry Extraction system is based upon the T136A and T136B modules from the 'DART' system product range. A simulation module provides a built in test capability for system performance validation and maintenance. Optional modules can be added to provide up to 128 user port.



Turning Visions into Reality

For further information please contact:
Satellite Services B.V.
Scheepmakerstraat 40
2222 AC Katwijk
The Netherlands
Tel.:(31)(0)1718-28120/28159
Fax:(31)(0)1718-27934

GOME: A New Instrument for ERS-2

A. Hahne, A. Lefebvre, J. Callies & R. Zobl
ERS Project Division, ESA Directorate for Observation of the Earth and Its Environment, ESTEC, Noordwijk, The Netherlands

The Global Ozone Monitoring Experiment, or GOME, is a new instrument that will be added to the original ERS-1 payload complement for the launch of the second European Remote-Sensing Satellite (ERS-2) in 1994. GOME is a nadir-viewing spectrometer which will observe solar radiation transmitted through or scattered from the Earth's atmosphere or from its surface. The recorded spectra will be used to derive a detailed picture of the atmosphere's content of ozone, nitrogen dioxide, water vapour, oxygen/oxygen dimer and bromine oxide and other trace gases. ERS-2's orbit will provide global Earth coverage every three days.

Introduction

In 1989, ESA decided to continue the ERS Programme beyond the expected lifetime of the ERS-1 satellite by approving the building and launch of the ERS-2 satellite. To provide the necessary continuity to the observations started by the instruments of ERS-1, ERS-2 is essentially a carbon-copy of the ERS-1 satellite. It was recognised, however, that there is an urgent need to investigate the composition and dynamic behaviour of the Earth's atmosphere. The ERS-2 Programme approval therefore included an experimental sensor for atmospheric research, the 'Global Ozone Monitoring Experiment' (GOME), which is essentially a scaled-down version of the SCIAMACHY instrument proposed for the European Polar Platform to be launched at the end of the century.

The inclusion of the GOME sensor in ERS-2 Programme was endorsed on the explicit understanding that:

- the sensor would be developed, tested, calibrated and integrated in the same time frame as the satellite and the other instruments would be rebuilt
- the resource demands of the sensor would have to be satisfied from the existing system margins, imposing stringent limitations on mass, power and data rate
- no major upgrades in the ERS Ground Segment would be needed, and the financial burden for the data-processing algorithms and software would be borne by scientific institutions and/or national agencies.

The limitations on resources have already led to drastic changes in the instrument concept, because at the Baseline Design Review held in February 1991 it became obvious that the power/energy demand exceeded the available margin. Instead of GOME having its own interface to the On-Board Computer (OBC) and to the Instrument Data Handling and Transmission (IDHT) system, it was decided to provide these functions via the existing interfaces of the Along-Track Scanning Radiometer (ATSR) instrument.

Scientific objectives

Ozone (O_3) is a tri-atomic form of oxygen, formed by hard ultraviolet radiation in the atmospheric layer between about 15 and 45 km altitude, the so-called 'stratosphere'. It absorbs radiation in the spectral region between 240 and 310 nm, preventing these harmful rays from reaching the ground in large quantities. This naturally protective atmospheric layer is now being threatened by human activities, in particular by the steady release of chlorfluorocarbons (CFCs) into the atmosphere. The accumulated anthropogenic effects on stratospheric ozone are believed to be causing a steady depletion of the ozone layer by approximately 0.3 % per year.

The chemistry of the stratosphere is very complex. The hard ultraviolet radiation causes the breakup of many of the available species into reactive fragments, which lead to a multitude of possible reactions. Normally, the rates of these reactions depend not only on the nature of the species, but also on local pressure, temperature, radiative fluxes in the different wavelength regions, vertical and horizontal transport processes, etc. Thus, in order to understand the ozone chemistry fully, it is not sufficient just to measure the ozone; one must also monitor the abundances of many other species, including very reactive intermediate species occurring in only very low concentrations.

Reflecting this need, GOME is intended to measure other species as well as to observe aerosols and polar stratospheric clouds which play significant roles in the heterogeneous processes associated with ozone chemistry. It is hoped that some of these species may be observed in the troposphere, another part of the atmosphere believed to be affected by man's activities. However, the presence of clouds may make this difficult.

For this GOME will exploit spectroscopy, which is a viable technique for observing trace species in the atmosphere. Sunlight, reflected by the ground surface and scattered within the different atmospheric layers, carries the absorption signatures of the absorbing species (Figs. 1 & 2). The GOME instrument is designed to collect this light over the entire wavelength region from 240 to 790 nm, in which not only ozone, but also a number of other atmospheric species absorb. In addition to the classical backscatter technique, the GOME instrument exploits the novel technique of 'Differential Absorption Spectroscopy' (DOAS)*.

Satellite mission and instrument accommodation

Like its predecessor ERS-1, ERS-2 will fly in a Sun-synchronous polar orbit with an inclination of 98°, with a mean altitude of 780 km and a local time of 10.30 h for the equator crossing on the descending node. This results in an orbital period of approximately 100 min and a ground speed for the subsatellite point of 7 km/s.

The GOME instrument's instantaneous field of view has been chosen to be 40 km x 2 km, or 2.8° x 0.14°. Via the

* Developed by U. Platt (Heidelberg, FRG).

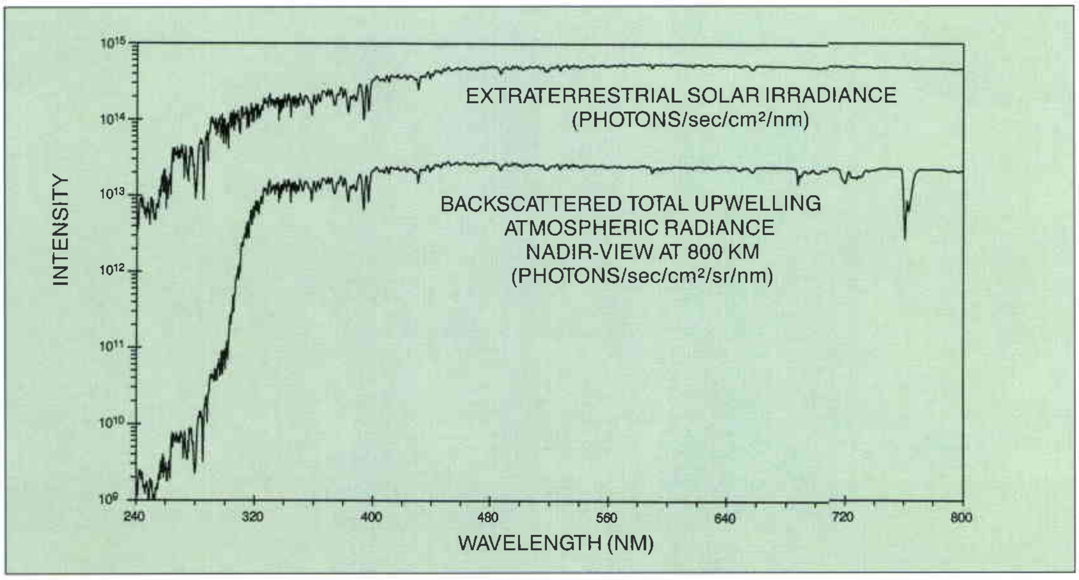


Figure 1. LOWTRAN simulation of spectral radiances at the top of the atmosphere in the wavelength range of the GOME instrument, i.e. 240–790 nm

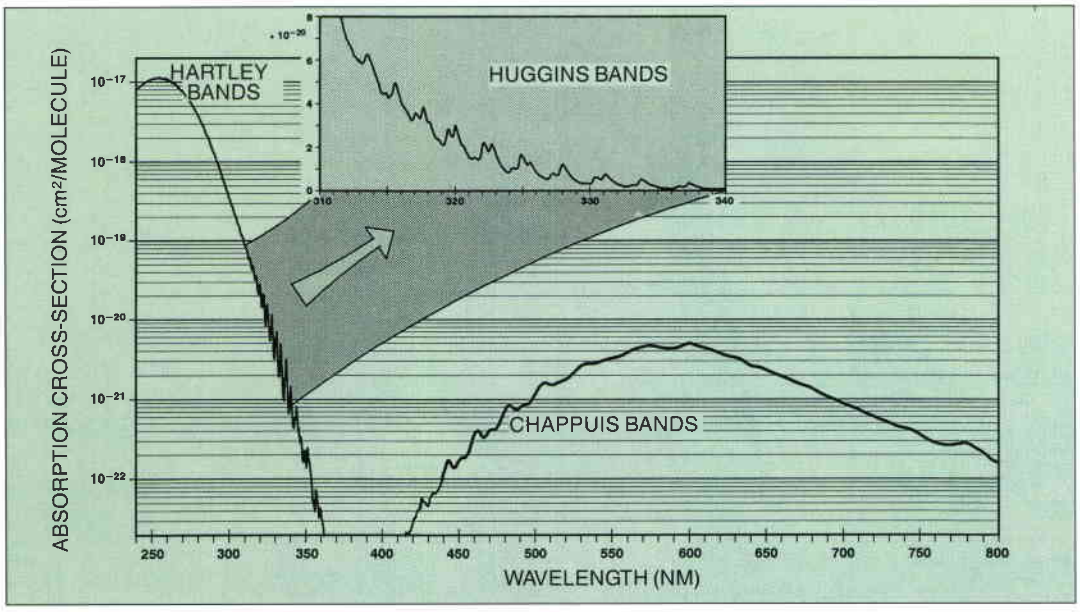


Figure 2. Ozone absorption cross-sections in the wavelength range of the GOME instrument

Figure 3. Artist's impression of the GOME instrument's scanning geometry

movement of the instrument's scanning mirror, this instantaneous field of view can be scanned across the satellite's track. With a ±31° scan, global coverage can be achieved within 3 days, except for a gap of approximately 4° around both poles. To overcome this limitation, a special pole-viewing mode has been included (Figs. 3 & 4a,b).

The GOME instrument is mounted externally, on the surface of the payload module facing in the flight direction (i.e. the −Y face), with a clear field of view in the nadir direction (Fig. 5). It is thermally decoupled from the spacecraft structure as far as possible.

Photon flux computations show that for the visible/near-infrared channels, a good signal-to-noise ratio can be achieved with a 1.5 s integration time on the detector. The time for one forward scan has therefore been set to 4.5 s. For the flyback of the scanning mirror, another 1.5 s have been allowed, resulting in the scan pattern shown in Figure 6, with a ground pixel size of 320 km x 40 km.

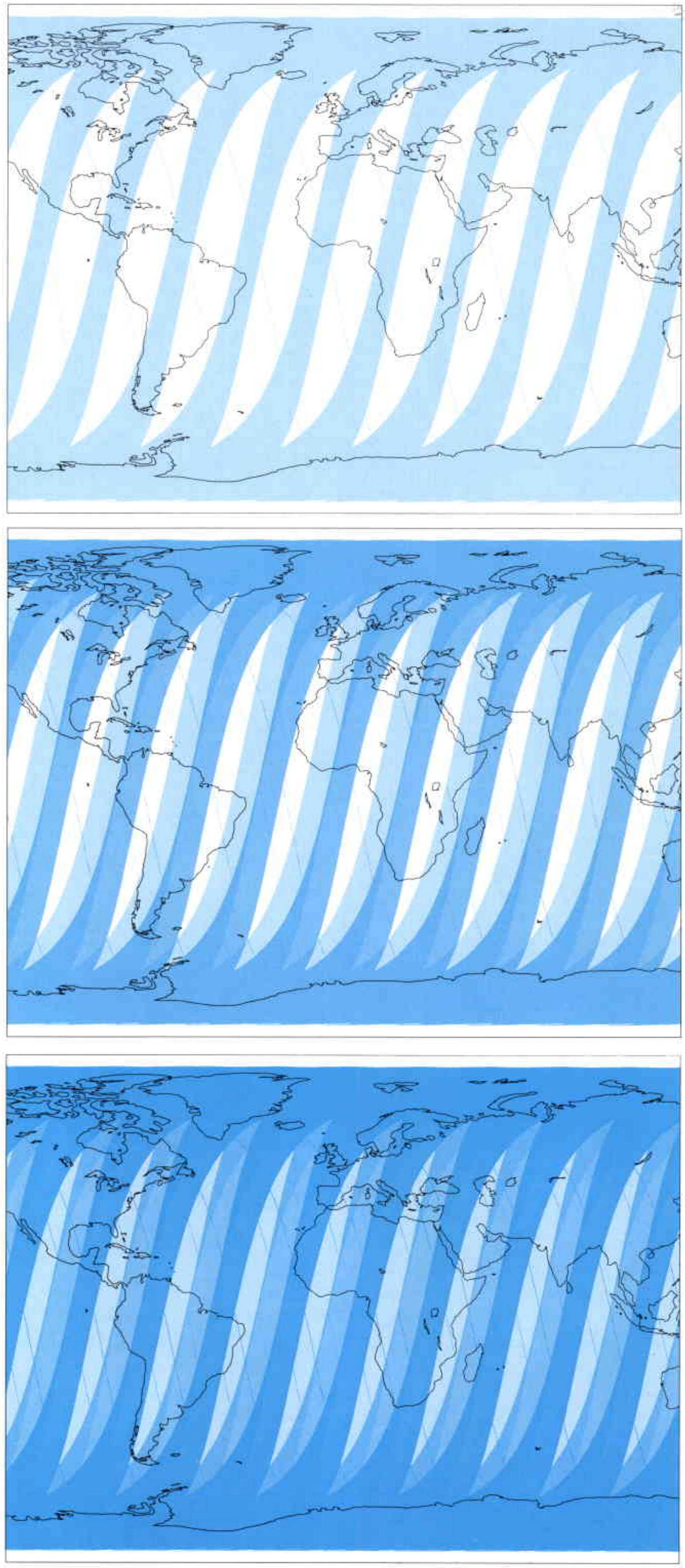
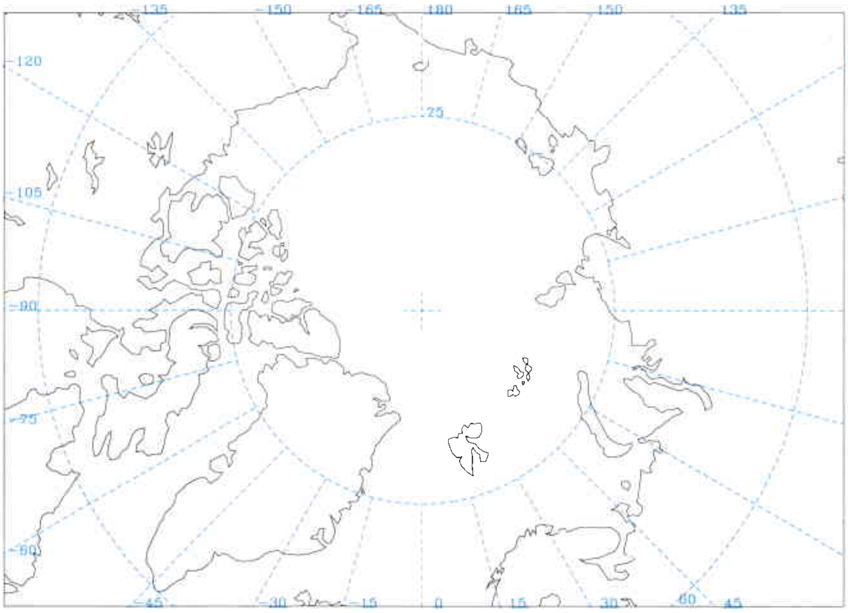
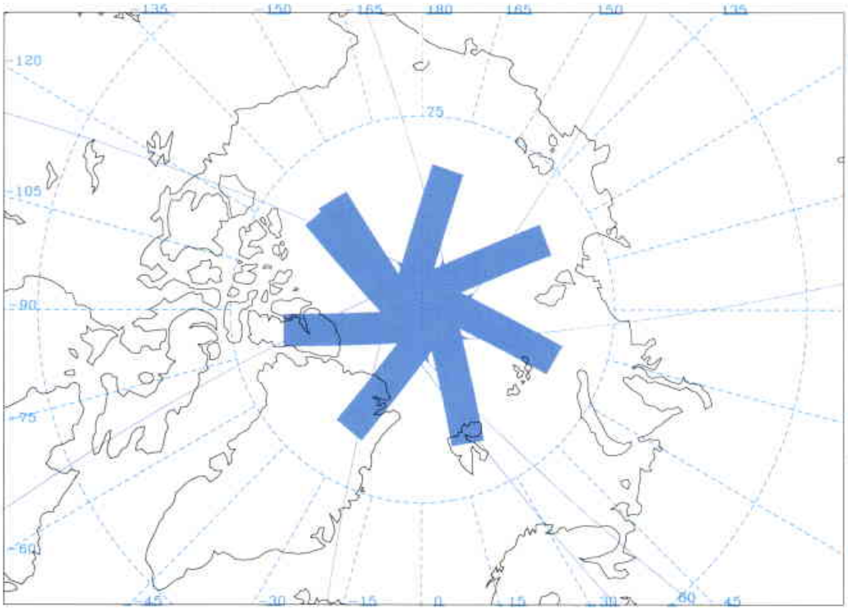
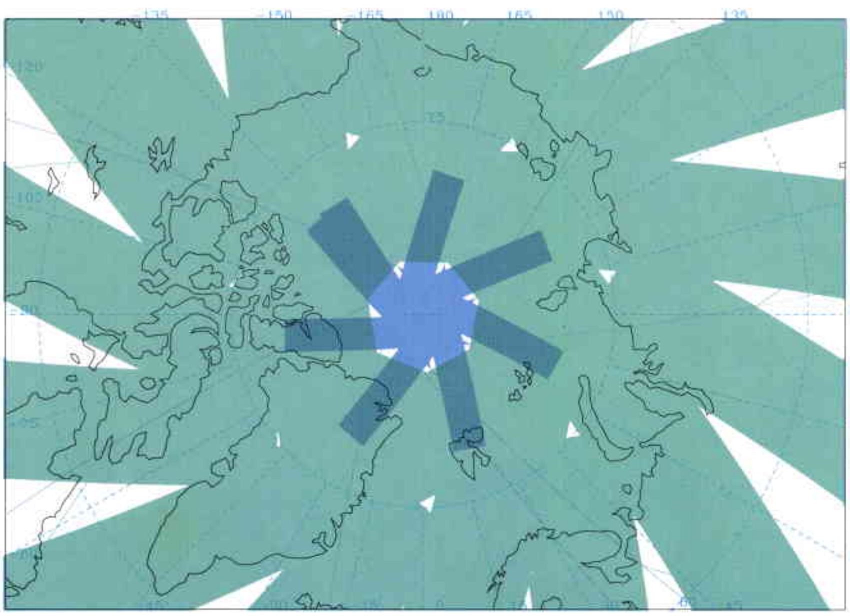


Figure 4a. Three-day coverage map for GOME







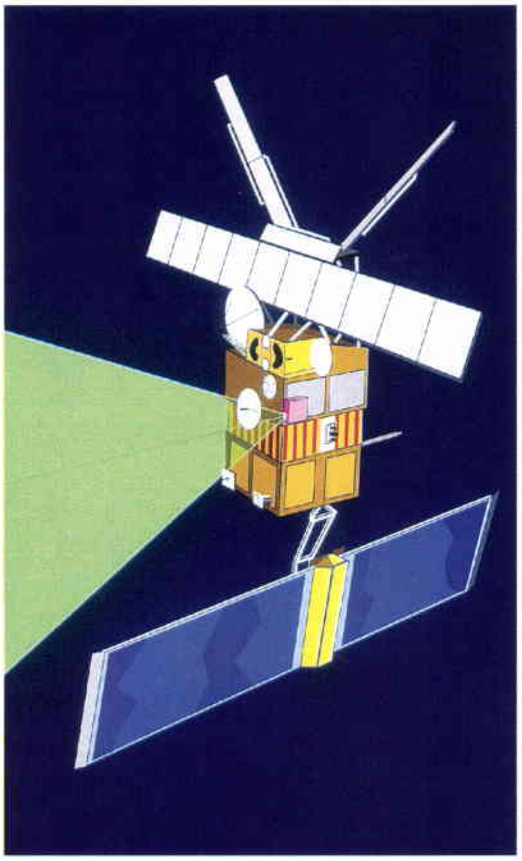


Figure 5. Artist's impression of the GOME instrument aboard ERS-2

The instrument's design

As a general principle, the GOME instrument collects light arriving from the Sun-illuminated Earth's atmosphere and decomposes it into its spectral components. In order to provide both the required spectral coverage from 240 to 790 nm and a good spectral resolution of 0.2–0.4 nm, this decomposition is done in two steps: first by a quartz pre-disperser prism, in which the light is split into four different channels. Each of these channels contains a grating as second dispersing element, and a 1024-pixel silicon array detector (the integration times on the chip can be multiples of 93.75 ms, with 1.5 s for the visible and 30 s for the ultraviolet being the default values).

The entire GOME instrument can be broken down into the following functional blocks:

- the spectrometer
- the four Focal-Plane Assemblies (FPAs)
- the Calibration Unit
- the scan unit with the scanning mechanism and the scan unit electronics (SEU) assembly

Figure 4b. Three-day coverage map for GOME

- the Polarisation Measurement Device (PMD)
- the Digital Data Handling Unit (DDHU)
- the optical bench structure
- the thermal control hardware.

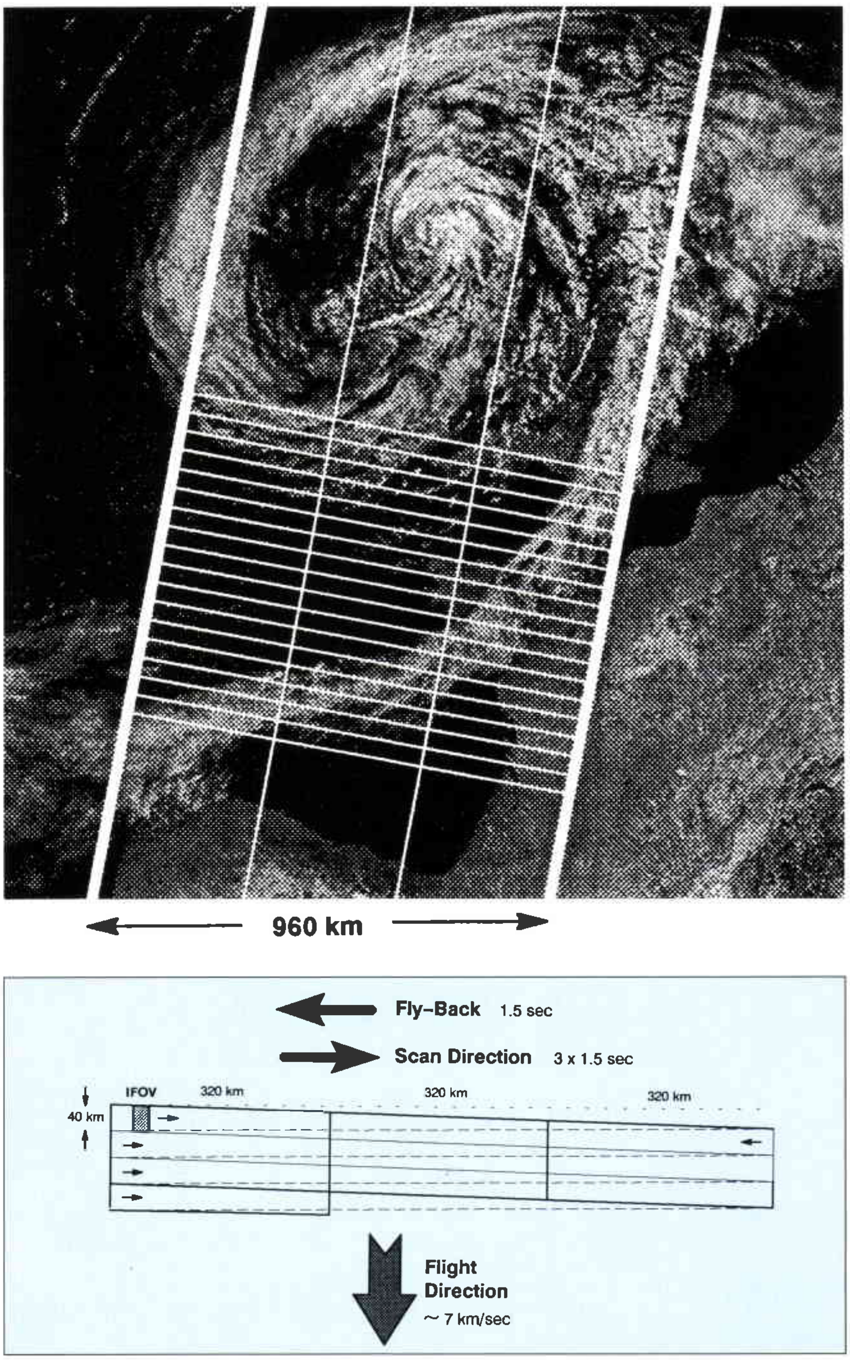


Figure 6. GOME scan pattern (graphic courtesy of DLR, Oberpfaffenhofen)

Table 1. Key optics performance parameters

Band	Wavelength range (nm)	Grating (l/mm)	Pixel resolution (nm)	Spectral resolution (nm)
1A	240—268	3600	0.11	0.22
1B	268—295			
2A	290—312	2400	0.12	0.24
2B	312—405			
3	400—605	1200	0.2	0.4
4	590—790	1200	0.2	0.4

Spectrometer optics

In the spectrometer optics, shown schematically in Figure 7, the light reflected off the scanning mirror is focussed by an anamorphic telescope such that the shape of the focus matches the entrance slit of the spectrometer (dimensions 10 mm x 100 μm. After the slit, the light is collimated by an off-axis parabolic mirror. It then strikes the quartz pre-disperser prism, causing a moderately wavelength dispersed beam. Another prism acts as channel separator: the upper edge of this prism reaches into the wavelength-dispersed beam, letting the longer wavelengths pass, reflecting the wavelength range 290–405 nm into Channel 2 by means of a dielectric reflecting coating, and guiding the wavelength range 240–295 nm internal to the prism into Channel 1. The unaffected wavelength range of 405–790 nm is then split up by a dichroic beam splitter into Channels 3 (400–605 nm) and 4 (590–790 nm).

Each individual channel consists of an off-axis parabola, a grating, and an objective with f-numbers of 2 (Channels 1 and 2) and 3 (Channels 3 and 4), finally focussing the light onto the detectors contained in their respective Focal-Plane Assemblies.

The most critical optical elements in the optical chain are the diffraction gratings, which have to provide both a high efficiency in the first diffraction order and a very low level of stray light and ghosting. Because of the criticality of the gratings for the final performance of the instrument, two parallel development programmes are under way, at the firms of Jobin-Yvon in France and Carl Zeiss in Germany. Some of the key performance requirements for the optics are summarised in Table 1.

Focal-Plane Assemblies

The FPAs are made from titanium and have a sealed quartz window at the side where they are flanged to the respective objective tubes. The rear side of the FPA, the so-called 'pin-plate', is a titanium plate provided with electrically isolated, vacuum-tight feed-throughs for the electrical connections to the detector. This is a Reticon RL 1024 SR random-access diode array detector with 1024 pixels, each pixel measuring 25 μm in the dispersion direction and 2.5 mm in the along-slit direction. Each diode is randomly accessible by an address bus and can be read out individually.

In the GOME instrument, the detectors of Channels 1 and 2 are split into several

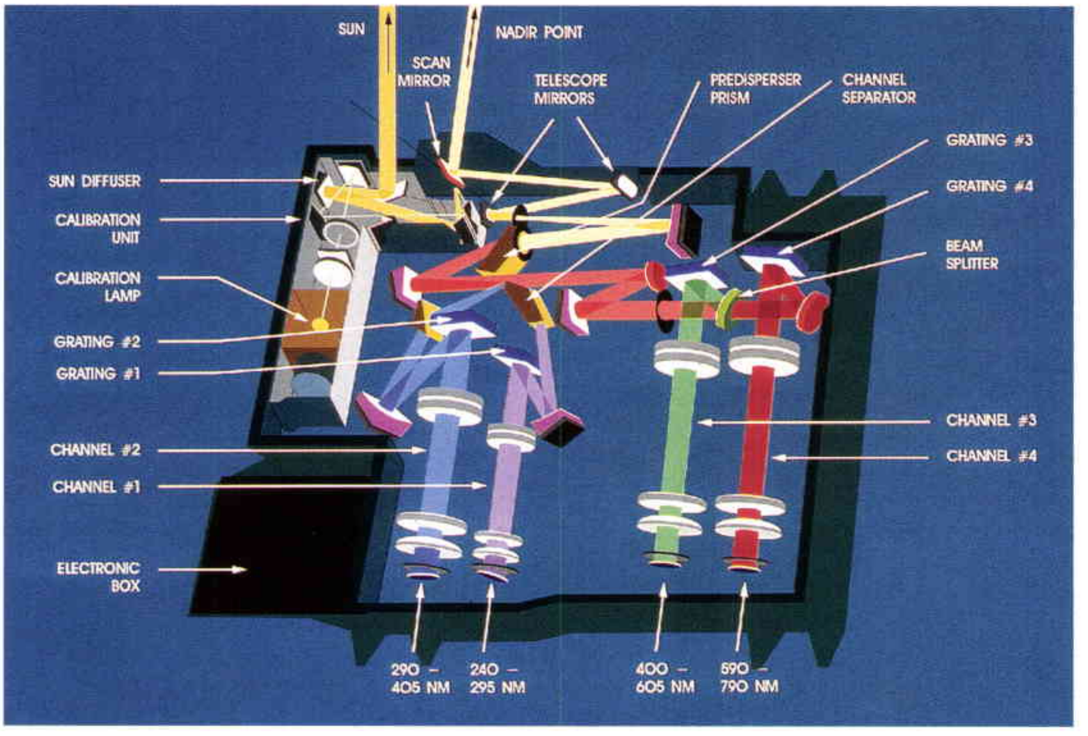


Figure 7. Spectrometer optics

bands, the integration times of which may be varied individually. The Reticon detector chip is shown in Figure 8. The detectors are glued onto two-stage Peltier coolers, which reduce their temperature to −40°C to keep the dark current of the photodiodes sufficiently low. The hot side of the Peltier coolers is glued (in the engineering model), respectively brazed (in the flight model), to a copper bar, extending through the pin-plate. Outside the FPA, this copper bar is connected via flexible connections and heat pipes to the main radiator. The tips carrying the Peltier coolers and detectors are tilted between 1.6° and 9.5°, to compensate for chromatic aberration.

At the back side of the FPA, the Front-End Electronics (FEE) are mounted on a printed-circuit board. They are based on a charge amplifier implemented with a low-noise amplifier and a dual-FET input stage. The output of the FEE is fed to the Digital Data Handling Unit (DDHU), where it is further processed and digitised.

During ground operations, the FPAs can be either evacuated, or filled with dry nitrogen to avoid moisture freezing out on the cooled detectors. In addition, the polarity of the Peltier elements can be inverted to heat the detectors to +80° to drive off possible contaminants and to anneal radiation effects. Once in orbit, the FPAs are exposed to the vacuum of space by a burst membrane, which is designed to open during the launch phase.

Calibration unit

In order to support the DOAS technique, one would like to have a wavelength stability of 1/100 th of a pixel. This is not achievable with a passive thermal design in such a power-limited situation. Instead, wavelength position on the detector pixels versus orbital temperature will be mapped by means of a hollow-cathode lamp (Pt-Cr-Ne) which provides a sufficient number of sharp lines in all wavelength regions.

For the radiometric calibration, the Sun will be used as the source. Because of the orbital and scanner geometry, which prevents direct viewing of the Sun via the scanning mirror, and because its high intensity would lead (even with the shortest possible integration time) to detector saturation, the Sun is viewed via a diffuser plate accommodated in the calibration unit (Fig. 9).

Previous NASA experience has shown that the diffuser is subject to degradation during its periods of exposure. Precautions are therefore taken by having:

Figure 8. Reticon RL1024SR detector chip

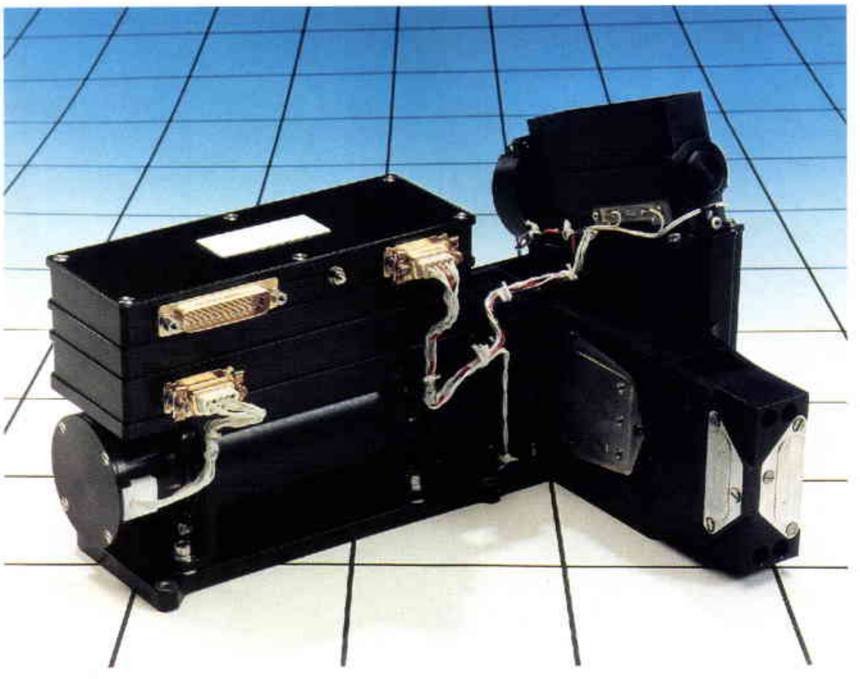


Figure 9. Calibration unit

- a mesh in front of the diffuser, attenuating the incoming light level and largely protecting the diffuser
- a shutter mechanism that opens only during Sun calibration and protects the diffuser during the remaining mission phases
- the possibility to view the calibration lamp via the diffuser, thereby having a means to monitor possible degradation, at least at those wavelengths provided by the lamp.

Scanning unit

The scanning unit consists of two separate assemblies, the Scan Mechanism (SM) and the Scan Unit Electronics Assembly (SUEA). The scan mechanism is located on the optical bench, with its rotation axis aligned with the satellite's flight direction. The axis carries a glued-on aluminium-coated mirror, which can be heated from the rear to drive off possible contaminants, if necessary.

A brushless DC motor actuates the scanner, the position of which is sensed by a resolver. The rotating part of the resolver, the mirror heater and the temperature sensor are connected to the static part via a flexible printed-circuit connection. The angular range of the scanner is limited to −63.8 to +192.2° with respect to nadir (0°) by software and end stops.

The rotation axis is supported by two spring-preloaded angular contact bearings, the balls of which are ion-plated with lead and the races are made of lead bronze. All structural parts (housing, pivot, etc.) are made from titanium.

Polarisation measurement device

The incoming light from the Earth's atmosphere can be partially polarised. Because the instrument's responses to the two orthogonal linear polarisation directions are not equal, there is a need to monitor the polarisation of the incoming light.

In the pre-disperser prism, light is internally reflected at the Brewster angle. About 5 % of this light, polarised normal to the plane of incidence, leaks away at this surface. This light is collected by an off-axis parabola, reflected by a mirror out of the plane of the optical bench, and then sensed by a custom-made photodiode array.

Because the device is not temperature-controlled, it is subject to drifts. To keep the impact of changing temperatures to a minimum, a second array of photodiodes with the same geometry, but not exposed to light, will be used to compensate for the dark current and its variability with temperature.

The measured signals are acquired by the DDHU, converted to digital signals, and included into the telemetry data (3 x 16 bit, 10.67 Hz).

Digital Data-Handling Electronics (DDHU)

The prime interface to the satellite's electrical subsystems is via the Digital Electronics Unit (DEU) of the Along-Track Scanning Radiometer (ATSR). Because the DEU now not only controls the ATSR's Infrared Radiometer (IRR) and Microwave Radiometer (MWR), but also GOME, a redundant DEU has been added, together with a DEU Switching Unit (DSU).

The DEU assumes all the normal functions of an Instrument Control Unit (ICU). Commands dedicated to GOME are expanded into a serial digital bit stream, initiating the appropriate actions within the DDHU. In the opposite direction, both housekeeping and scientific data are written by the DDHU into data buffers, from which they are requested by the DEU to be put into predefined fields of the ATSR S-band and X-band data streams.

Thermal-control hardware

The most critical aspect of the thermal control is the detector temperature, which is provided by the Peltier elements in each of the Focal-Plane Assemblies. The hot sides of the Peltiers are all connected, via copper bars and flexible connections, to a parallel pair of bent heat pipes, which end in the primary radiator exposed to deep space.

The DDHU and the scanning mirror electronics assembly have their own radiative surfaces for thermal control. The remainder of the instrument is wrapped in multi-layer insulation blankets. For cold non-operational phases, thermostat-controlled heater mats and resistors are directly powered from the payload's Power Distribution Unit.

Structure

All elements of the optics, mechanisms, electronics and thermal hardware are mounted on the optical bench, which is a nearly rectangular aluminium plate with stiffening ribs beneath. This optical bench is carried on four feet, one of which is round in cross-section and rather stiff. The other three are blade-shaped feet, with their flexing direction lying in the direction of the fixed foot. This prevents mechanical distortion of the optical alignment due to thermal expansion of the bench.

Beneath the optical bench, in the space between the ribs, the harness and the pipework for FPA evacuation are routed. An EMC shield protects the instrument from electromagnetic interference from the satellite's radars and communications system.

Operations

The GOME instrument has numerous measurement, calibration, and support modes. In particular, due to the varying light levels that will be experienced during each orbit, integration time settings will have to be adjusted frequently. In addition, once per day a Sun calibration has to be performed.

In order to limit the command traffic on the uplink, the DEU stores three different timelines, each of which can be activated automatically up to 16 times in sequence. One of these timelines is for normal operations, one for an orbit in which a Sun calibration is being performed, and one with a sidewards swath to cover the polar area (with the normal nadir-centred swath there would be a gap in coverage of about 4° around both poles).

About once per month, a wavelength mapping as function of the thermal variations will be performed with the wavelength calibration lamp. On these occasions a diffuser characterisation can also be carried out.

Lunar observations, which are restricted by the Sun–Moon–satellite scanner field-of-view geometry, will be performed whenever possible.

Data processing

GOME data will arrive together with the other 'low-bit-rate' data at the various ground stations to which the ERS tape recorders are downlinked. Extracted GOME data, together with orbit and attitude information, will then be shipped on Exabyte cassettes to the German Processing and Archiving Facility (D-PAF) in Oberpfaffenhofen. In a first processing step, the raw data will be corrected for instrument-induced errors and drifts, and provided with information on geo-location, Sun aspect angle, etc.

From these radiometrically and wavelength corrected geo-located spectra, the ozone total column amount, ozone vertical concentration profile, and data on aerosol loading and cloud cover can be retrieved. This will be done at distributed centres, according to the particular scientific expertise available. Time and budgets permitting, other atmospheric-constituent retrieval can be added to the range of data products generated. Finally, time and spatial averaging for long-term global-trend analyses is likely to be conducted (not yet specifically defined).

In addition to this off-line processing chain, some limited processing capabilities will also be installed at ESTEC, in order to evaluate the instrument performance after launch, optimise parameter settings and operating schemes, and to support possible scientific campaigns.

GOME should produce unique data as there will be no other instrument available on its time scale which duplicates its capabilities. The instrument fills a critical slot as far as future observing strategies are concerned, and GOME could well become the prototype for subsequent ozone-monitoring instruments. Its medium spectral resolution combined with a wide spectral range and absolute calibration is particularly important as it means that, in addition to applying the traditional backscatter approach, one can also use differential optical absorption spectroscopy to retrieve data with GOME.

Acknowledgements

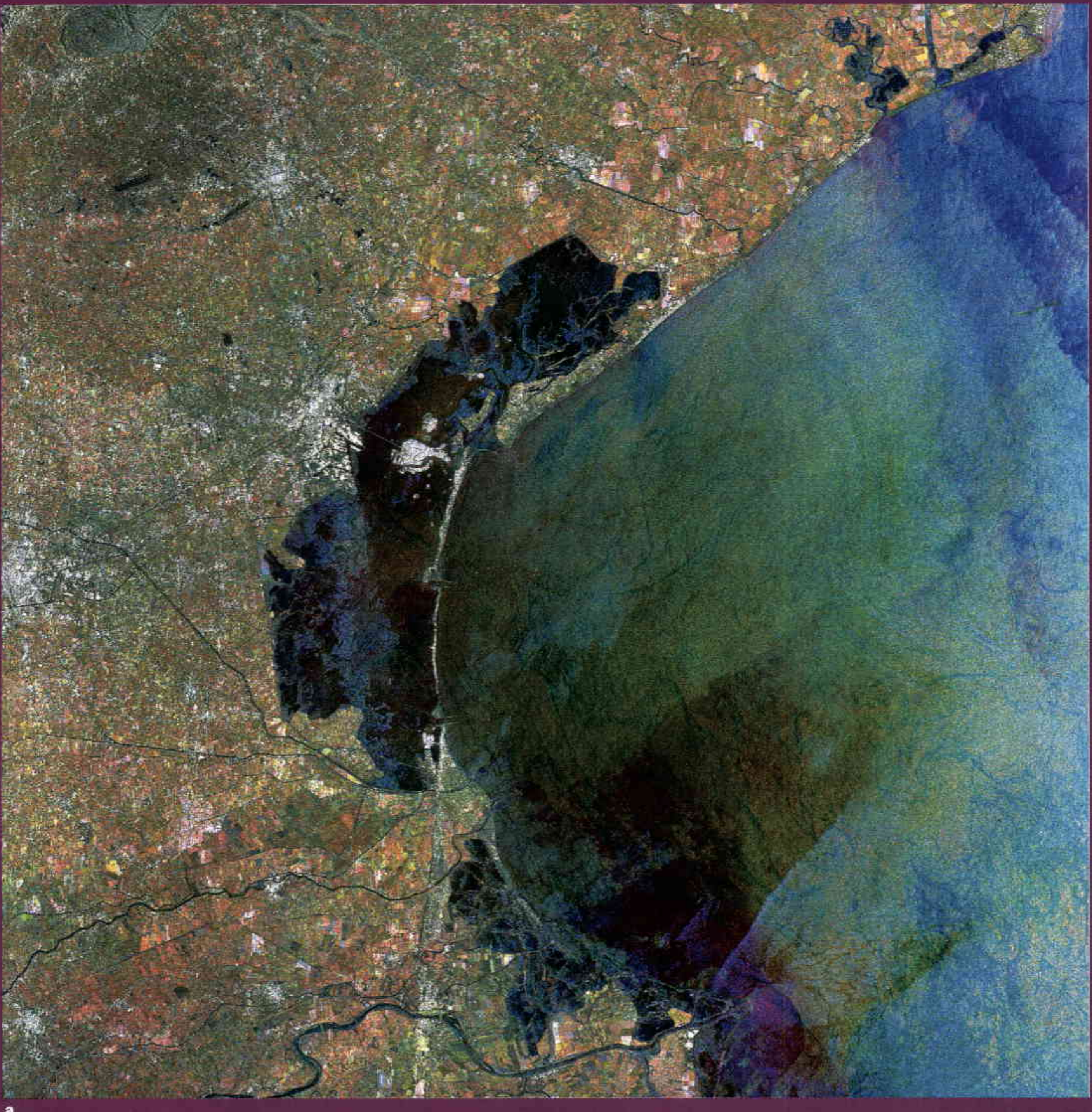
We gratefully acknowledge the unfailing support of the GOME Science Team, headed by Prof. Dr. J. Burrows from the University of Bremen (D). Much of the work reported here has been done by the GOME Industrial Team, comprised of Officine Galileo (I), Laben (I), TPD/TNO (NL), Dornier (D) and the Rutherford Appleton Laboratory (UK), and BAe (UK) for the DEU modifications.

Focus

ERS-1 Imagery of Venice

ERS-1 carries a single Synthetic Aperture Radar (SAR) microwave channel generating a black and white image. The colours in the image shown here result from the superimposition of data from three ERS-1 passes; data acquired on 10 May 1992 has been assigned to the blue, that of 23 August to the green, and that of 27 September to the red. The response of a target depends on its geometry (surface roughness for fields; vertical structure for urban areas) and dielectric behaviour (material, water content). Areas that retained the same backscattering throughout the imaging period are shown in white or some grey level, while changes are highlighted by colour.

No change is observed either in built-up areas (light in grey and white), in woodlands (deciduous trees in grey, pines dark grey), or in pasture land (appears very dark as it represents a smooth surface in microwave terms). Ground verification would be needed to establish an interpretation key for field crops. Typical crops in the region include wheat, corn, sugarbeet, soya and, in the northern part, tobacco. Orchards and vineyards are also common. Magenta could, for example, represent wheat fields, fully vegetated in May and ploughed (rough surface) in September. Fields appearing red or yellow are likely to be late crops such as corn or sugarbeet. The green areas might be orchards.



a

Earth

The colours in the Adriatic Sea are driven by the roughening effect of the wind at the times of data acquisition. Wind conditions were light on both the first and last dates, but stronger on the intermediate date, which is probably why the long dark features do not appear on that day. They are believed to be oil films produced by micro-organisms, floating on the water and damping the effect of the wind. They indicate sea circulation, both horizontally via their elongated form and vertically via their local concentration.

The tiny coloured dots in the sea and in the harbours of Venice and Mestre are ship positions on the different dates; the red spots, for example, reveal ships that were present only on 27 September.

Even this brief analysis of a multi-temporal ERS-1 SAR image shows that such data can be very usefully employed for many kinds of environmental monitoring.

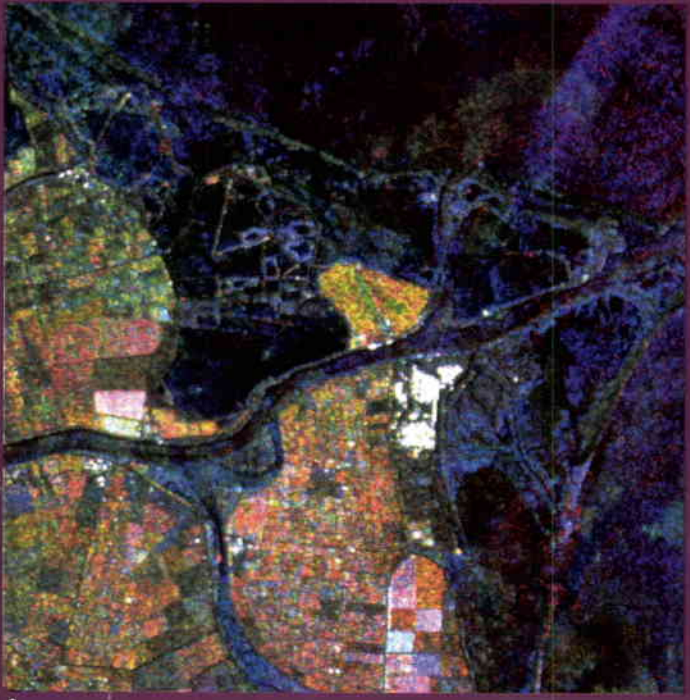
b

(a) Multi-temporal ERS-1 SAR image of the Venice region and bay acquired at Fucino (I) on 10 May, 23 August and 27 September 1992 at 09:59 UTC, and processed by the Italian ERS-1 Processing and Archiving Facility, in Matera (image centre: 45-23 N, 12-29 E).

(b) Enlargement of Venice and the harbour of Mestre. The Grand Canal and San Marco Square are picked out by the SAR. The coloured dots in the harbours are ships that were present during at least one of the ERS-1 passes.

(c) Enlargement of the Po Estuary, with the sea appearing in magenta. Crops can be distinguished by their colour. The bright irregularly shaped area contains building complexes.

(d) Enlargement of the coastal area, with the Venice Lido on the left. The well-developed natural oil slicks visible with light winds blowing may help in understanding the sea circulation mechanism.



c

d

The Giotto Extended Mission (GEM) – High Risk, High Payoff

H.R. Nye*
Mission Operations Division, European Space Operations Centre (ESOC), Darmstadt, Germany

A. Morani**
Space Engineering, Rome, Italy

After Giotto's successful first mission to encounter Comet Halley in 1986, the prospects for an extended mission looked bleak. A number of potential targets had been identified, all requiring the battered spacecraft to operate outside its intended design envelope. The preferred second target, a little-known comet called Grigg-Skjellerup, could be reached in July 1992, but under conditions that would not only require good fortune, but would also entail a high degree of ingenuity in the way in which the mission would have to be conducted.

The mission to Comet Halley

Early operations and the cruise phase

On 2 July 1985, an Ariane-1 lifted the Giotto spacecraft (Fig. 1), with its complement of ten scientific instruments and loaded with 69 kg of hydrazine, into a geostationary transfer orbit. One day later, and marking ESA's first endeavour into interplanetary space, the spinning spacecraft was boosted into heliocentric orbit, to start a nine-month journey towards an encounter with Comet Halley.

As ESA's contribution to the international flotilla of spacecraft that was being sent to greet the comet, and in view of the great distance that the spacecraft would have to travel, often out of ground contact, Giotto was equipped with a high degree of onboard autonomy. This would not only ensure a safe passage to Halley, but would also allow the spacecraft to recover from any failures that might befall it during the cruise phase. This autonomy included:

- Full redundancy in power conditioning and distribution, in transmitter and receiver hardware, in data-handling hardware and software, in the attitude and orbit control electronics, in the thermal heaters, and in the despin mechanism electronics responsible for keeping the offset dish of the spacecraft's High Gain Antenna (HGA) in an Earth-pointing direction.
- Application programmes to select and configure all redundant spacecraft hardware in order to recover from successive combinations of failures in different subsytems.

As the spacecraft–Sun–Earth geometry was changing daily during the cruise phase, it was necessary to define an attitude corridor through which to fly the spacecraft (Fig. 2). This sometimes very tight corridor was defined by the attitude (solar aspect angle) necessary to provide, simultaneously, sufficient power from the body-mounted solar array and an acceptable thermal environment, and to ensure that contact with the Earth using the High-Gain Antenna was allowed. It was therefore necessary for the ground to perform routine attitude manoeuvres (on a daily basis after November 1985) to respect the attitude constraints and to keep the HGA pointing towards Earth.

The spacecraft was designed to be controlled primarily from the ground, but had to be able to survive onboard failures and possible ground outages lasting several days. The features implemented onboard to provide for this included:

- Application programmes to control spacecraft attitude and spin rate within safety limits, using Sun sensor data.
- Application programmes to recover from loss of contact with the ground, by selecting the redundant transmitter and manoeuvring to an Earth-pointing attitude using star-mapper information.

For the various applications programmes to function correctly, it was necessary for the ground to inform the spacecraft of the relevant limits for attitude, spin rate and Earth direction, applicable for up to fifteen days in advance, on a daily basis.

* GEM Flight Operations Director.
** GEM Spacecraft Operations Manager.

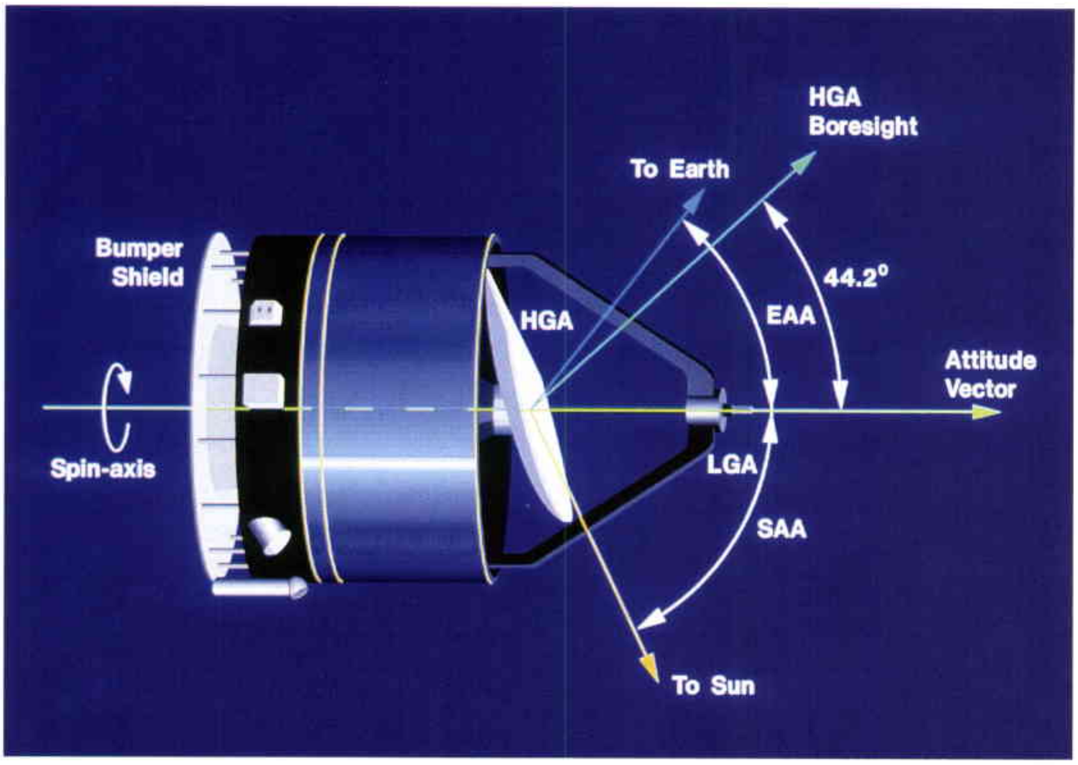


Figure 1. The Giotto spacecraft

All spacecraft operations during the mission to Comet Halley were conducted from ESOC using the facilites of the Multi-Satellite Support System (MSSS) for satellite monitoring and control. Initial telemetry and telecommand contact with the spacecraft (through the low-gain 'omni-directional' antennas) was established using facilities of the ESA S-band network of ground stations at Malindi in Kenya, Carnarvon in Australia, and Kourou in French Guiana. After activation of the HGA early in the cruise phase, station support was provided by Carnarvon and DLR's Weilheim station in Germany for S-band uplink and S- and X-band (360 bit/s non-science) downlink.

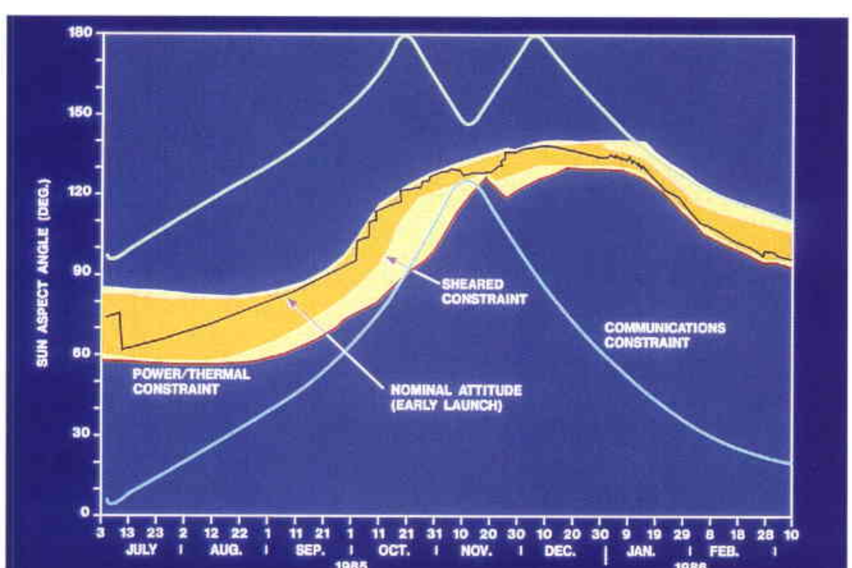
All flight-dynamics activities, involving definition of the attitude strategy and manoeuvres, and definition of the orbit manoeuvres necessary to keep the appointment with Halley, were also conducted from ESOC.

Additional support had been arranged for this important mission, using stations of the NASA Deep-Space Network (DSN) 26 m system to provide tracking and back-up commanding support. Due to the differences between the ESOC MSSS and the NASA Jet Propulsion Laboratory (JPL) command processing systems, it was necessary to develop a Giotto command database for installation at JPL and to install an emulated JPL command terminal at ESOC, through which emergency commands could be uplinked.

The backup command facility was required two days after launch when it became clear that spacecraft temperatures were falling more rapidly than had been anticipated, due to excessive heat radiation from the nozzle of the expended boost motor. Commands to fire pyrotechnic devices releasing sprung shutters to close off the exposed nozzle were the first to be sent using the JPL DSN link, as no ESA station had visibility at the time.

All cruise operations were successfully executed, and included an extremely active period of cruise science not foreseen before launch. Science data at 5.7, 23 or 46 kbit/s was downlinked to the 70 m Parkes Radio Telescope, modified for X-band telemetry reception, in Western Australia. Data was

Figure 2. Spacecraft attitude constraints during cruise



routed in real time to ESOC, where quick-look analysis was performed on Experimenter-provided equipment. Two periods were set aside in the cruise phase for 'encounter rehearsals', during which the full scenario of encounter operations was exercised, involving all parties including NASA, which was to provide hot-standby coverage of the encounter period using stations of the DSN 64 m network.

Encounter operations

Giotto had other safety features intended for use on arrival at the comet incorporated onboard, to ensure full real-time science-data recovery at the time of closest approach to Halley. This was particularly important as the ability to react to anomalies onboard would be limited by the 16 min round-trip light time, and fears that an uplink from the ground would be corrupted in the region of the comet suggested that commands might not get through correctly. The features designed to provide the degree of autonomy required included:

- Full redundancy in power conditioning and distribution, in data-handling hardware and software, in the despin-mechanism electronics, in the attitude and orbit control electronics (required to provide Sun pulse information to the despin electronics to maintain High Gain Antenna pointing) to ensure continuity in the provision of services to all experiments and subsystems throughout the encounter, and controlled by a combination of application programmes and hardware watchdogs.
- A redundant X-band Travelling Wave Tube (TWT) operated in warm-standby and automatically switched over within a matter of milliseconds in the event of failure of the prime TWT.
- Application programmes to monitor all experiments and thermal-control heaters and ensure that they remained switched on throughout the encounter.
- Four batteries capable of supporting full payload operation for at least 2 h in the event of a total solar-array failure due to cometary dust damage during the encounter (maximum capacity 64 Ah).
- An outer and inner sacrifical bumper shield to protect the experiments from dust-impact damage at closest approach.

At encounter, the spacecraft would meet Halley head on at 68 km/s, flying with its bumper shield perpendicular to the relative-velocity vector, to maximise the protection it afforded against cometary dust. The geometry at encounter was such that the HGA had been designed so that its beam was offset at an angle of 44.2° to the spacecraft's spin axis to allow real-time telemetry transmission to the ground (Fig. 3).

Targetting of the spacecraft was finalised at the request of the experimenters, defining the spacecraft–Halley miss distance as 540 km (±40 km, one sigma), at a distance of 140 million kilometres from the Earth, at 00:11 GMT on 14 March (ground receive time). Accurate targetting was made possible by the provision of last-minute data on the position of the comet by the Russian Vega-1

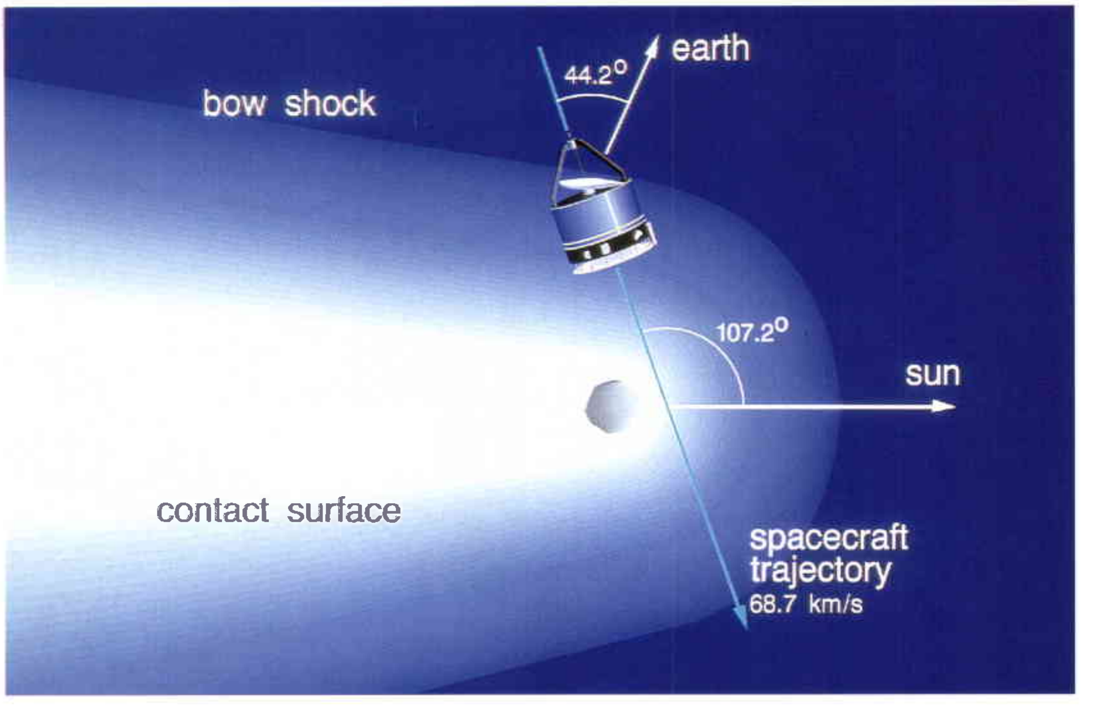


Figure 3. Schematic of the encounter geometry

and Vega-2 spacecraft as they flew by Halley some days before Giotto. This represented the final stage in the 'Pathfinder' activities of the Inter-Agency Consultative Group (IACG) set up to coordinate Halley targetting, and required close liaison between ESOC's flight-dynamics specialists and their Russian counterparts on the Vega missions.

Encounter operations commenced at 18:34 GMT on 13 March 1986, when the Carnarvon station acquired visibility of the spacecraft for commanding. Spacecraft telemetry at 46 kbit/s in X-band was received both at Parkes and at the DSN Tidbinbilla 64 m station in Australia. The DSN also provided a commanding capability in hot-standby. Three hours before closest approach, all commanding had been completed and the spacecraft and experiments were ready and set up for the encounter. Any mode changes to the experiments required during the course of the encounter would be effected by time-tag commands already loaded onboard.

The science returned in real time during the approach to the comet was beyond all expectations: the Halley Multicolour Camera had started to track the comet as early as 21:02 GMT and was to deliver extraordinary images of the nucleus. Evidence of the cometary dust had been detected at 23:09 GMT, about an hour before closest approach, increasing in abundance all the way. At 6 min before closest approach, dust impacts had been detected on the rear bumper shield, indicating that the front shield had been penetrated. At 4 min before closest approach, there were noticable variations in spacecraft attitude. At −3 min 10 sec, the star-mapper output failed. At −7 sec, the TWT switched over, probably in response to electrostatic discharge, while at −5 sec Parkes lost lock on the downlink, resulting in telemetry blackout.

The spacecraft had apparently been knocked off balance by the impact of the dust and was wobbling wildly, taking the HGA beam away from the Earth. The passive nutation dampers onboard the spinning spacecraft took more than 30 min to stabilise the situation before telemetry was reacquired, and a first status assessment showed the spacecraft to be still functioning despite its ordeal. Although the Halley Multicolour Camera had ceased to track the nucleus only minutes before closest approach, science operations continued on the out-bound journey for a further 12 h, at which point the experiments were finally deactivated from the ground.

Giotto had successfully fulfilled its mission to Comet Halley in a most spectacular fashion.

Post-encounter damage assessment

The Giotto mission to Comet Halley had always been referred to as a kamikaze mission as the spacecraft had not been expected to survive the encounter: no plans had been laid for further operations, but daily operation of the battered spacecraft continued whilst the encounter damage was assessed. All attitude manoeuvres performed after encounter were successful, but several

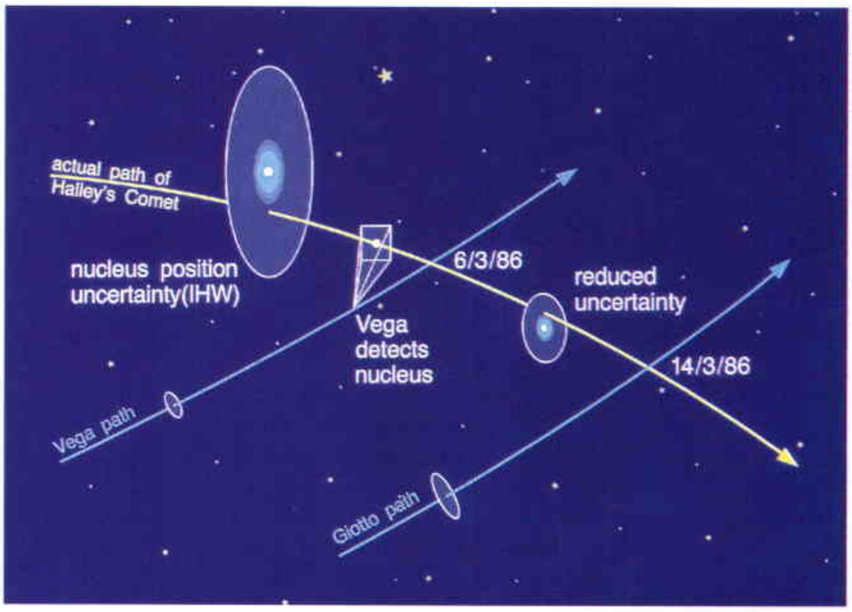


Figure 4. The 'Pathfinder' concept

parts of the spacecraft had been damaged, most notably:

- the spacecraft structure, resulting in a permanent spin-axis offset and wobble
- the star-mapper light baffle, resulting in erroneous star pulses on the sunward side of the spacecraft, and making all autonomous Earth-seeking manoeuvres unusable
- the electric power-control system and power dumpers, resulting in instability on the main bus (surprisingly, the solar array had not been affected by the dust as had been feared)
- the thermal-control blankets, resulting in radical changes in the spacecraft's thermal behaviour.

Hibernation I

The spacecraft had survived, and was still carrying 60 of the original 69 kg of fuel loaded before launch, owing to the injection accuracy achieved both initially by Ariane and later by the onboard boost motor: this fuel could potentially allow consideration of a future mission. What sort of mission was not clear, but regardless of whether plans for the future existed or not, resources did not permit continuous control of the spacecraft and a plan to hibernate Giotto was devised and implemented at the beginning of April 1986.

The hibernation strategy was to place the spacecraft in an Earth-return orbit, to manoeuvre it into an attitude intended to minimise the temperature excursions experienced in the summer and winter as Giotto journeyed around the Sun once every ten months, and then to deactivate it. After five orbits, Giotto would return to the vicinity of the Earth in the middle of 1990.

By 2 April 1986, all hibernation operations had been executed, and the spacecraft was configured into a minimum-power mode, with autonomy features enabled for the detection of possible equipment failures: the transmitter was switched off leaving Giotto to look after herself for the next four years.

In the meantime, a search for potential cometary targets was initiated. One of a number of promising options was a little-known comet called Grigg-Skjellerup, which was reachable in 1992.

The Giotto Extended Mission (GEM)

Reactivation I

Before making any commitments to a future mission, ESA needed to make a thorough check on the state of Giotto's scientific instruments. This had not been done after the Halley flyby, as the science community was then fully occupied with analysis of the encounter data. Such a checkout would necessitate reactivation of the spacecraft, something that had never before been attempted.

Thus it came to pass that in February 1990 the long process of reactivation was started, as Giotto made its approach towards Earth. The spacecraft had been dormant for four years, had been subjected to cyclic extremes of temperature and was at an unknown attitude, and one which precluded communication via its High Gain Antenna (HGA). There was only one way to communicate with Giotto and that was via the omnidirectional Low Gain Antenna (LGA) mounted on the top of the spacecraft.

The LGA had been designed for communication in the first days after launch into transfer orbit, and commands could be received only if uplinked through the largest antenna in NASA's Deep-Space Network, using a transmitter power approaching 100 kW. The same huge antenna would be needed for detection of the weak radio-frequency (RF) signal that could be radiated from this tiny antenna, but telemetry would not be available.

A reactivation strategy was devised that would take Giotto through a number of similar cycles, each designed to manoeuvre the spacecraft in the blind until contact via the HGA could be established. Each cycle differed in the onboard units selected to do the job, as there was no way of determining a priori which units were operable after four years in hibernation.

The first reactivation activities, however, would involve identification of the presence of Giotto at some 100 million kilometres from Earth. The DSN swung its Madrid antenna, by now upgraded from 64 to 70 m, in the direction where Giotto was predicted to be and, using the JPL Command System Terminal located at ESOC, the process of configuring the spacecraft for a downlink via the LGA was started. After 2 h, Madrid reported acquisition of a weak signal (−166 dBm), but also that there was a noticeable 'wobble' on the downlink frequency.

Analysis showed that this frequency wobble (Doppler) could be used to determine the spacecraft's spin rate, as it was due to the fact that the LGA was now no longer aligned with the spacecraft's spin axis, which had become offset as result of mass loss during the Halley encounter. It also transpired that the Doppler could be used to determine if the HGA's despin mechanism activated or not, and if the later spacecraft manoeuvres were being executed correctly. All of this was being achieved in the absence of telemetry!

This information allowed the ground controllers to accelerate the reactivation process such that full control of the spacecraft was established through the HGA some 150 h after starting. The combination of manoeuvre modes selected to bring the spacecraft into an Earth-pointing attitude were not originally foreseen by the spacecraft manufacturers, but the plan was to control spin rate and solar aspect angle simultaneously, whilst performing a constant solar-aspect-angle precession: Giotto again performed beyond its design envelope.

All was not well, however, as the Control Centre in Darmstadt counted the cost of 4 yr of hibernation: a power converter supplying the despin mechanism and the Attitude and Orbit Control System (AOCS) was dead, and one Central Terminal Unit (CTU) was unable to generate spacecraft telemetry. Redundancy was therefore reduced in these areas.

That was not all: the spacecraft had been reactivated as it approached perihelion, and was unbelievably hot. Measures were taken to reduce the temperatures of critical units by manoeuvring the spacecraft into a more favourable attitude. Time was running out, however, as Giotto was rapidly approaching Earth, and payload checkout had to be completed before targetting the spacecraft for Comet Grigg-Skjellerup.

Experiment checkout

At the end of April 1990, spacecraft temperatures had reduced to levels at which the experiments could be activated, and checkout began. An additional complication arose when, due to the spacecraft's now increasing distance from the Sun and the unfavourable solar aspect angle required to maintain Earth contact whilst also ensuring that onboard temperature levels remained acceptable, the solar array was unable to provide sufficient power for Camera checkout at 46 kbit/s at X-band.

The only option was to use the less power hungry S-band downlink, but this had never been designed for bit rates other than 360 bit/s, and its use was only feasible at all because of the still diminishing Earth range. More or less as an experiment, the S-band system was configured and the telemetry bit rate cranked up to 23 kbit/s. In this configuration, Camera testing was completed and once again Giotto had proved to have hidden capabilities that were unknown before launch.

The checkout programme showed that, of the original ten experiments, three were fully functional (Magnetometer, Energetic-Particle Analyser and Optical Probe Experiment), three were partly damaged, but usable in a future mission (Johnstone Plasma Analyser, Ion Mass Spectrometer and Dust-Impact Detector), and two were too damaged to be of any further use (Halley Multicolour Camera and Neutral Mass-Spectrometer). A further experiment, the Rème Plasma Analyser, although not dead, seemed to be tripping the spacecraft Data-Handling System Watchdog. The Particle-Impact Analyser, although undamaged during the Halley encounter, would be of little use as the geometry foreseen for the encounter with Comet Grigg-Skjellerup would be unacceptable.

Earth swingby

Once experiment checkout had been completed, the Control Centre made preparations for targetting the spacecraft towards Comet Grigg-Skjellerup. This would be no ordinary manoeuvre, as the Earth's gravitational field was to provide the kick needed to bring Giotto into the otherwise unreachable orbit. At 10:00 GMT on 2 July 1990, exactly five years after its launch, and with the Magnetometer and Energetic-Particle Analyser activated, Giotto flew over the Earth at an altitude of 22 000 km, and made space history once again. It was on its way to meet Comet Grigg-Skjellerup on 10 July 1992.

The Earth swingby increased the spacecraft's orbital period from 10 to 13 months, and would take Giotto further away from the Sun than it had ever been designed to go. This increased distance from the Sun would severely limit the power available from the solar array, making further continuous operation of the spacecraft once more impossible. It was therefore necessary to put Giotto into hibernation for a second time.

Hibernation II

This time, the hibernation attitude and Earth–spacecraft geometry fortuitously allowed the ground to monitor the final attitude manoeuvre and perform tracking over several days until 23 July 1990, when contact was terminated. This provided the Control Centre with accurate knowledge of the spacecraft's attitude and orbit at the start of Hibernation II, which would be particularly useful in planning any future reactivation.

The hibernation configuration this time was more spartan than before: the single functioning despin electronics unit was switched off, the damaged CTU was used in favour of the working one, and all heaters allowed by the reduced power level in hibernation were switched on. Further unit failures could not be tolerated if a future mission was to succeed.

In this phase of the mission, contact with the spacecraft had been established using a combination of stations, depending on Earth range, downlink mode (S- or X-band) and bit rate, and included three DSN stations (Goldstone in California, Madrid in Spain, and Canberra in Australia), DLR's Weilheim station in Germany and ESA's Perth station in Australia (moved from Carnarvon).

Giotto was to remain in hibernation for two years: on hearing the state of the spacecraft and the results of the experiment checkout, ESA had no difficulty in 1990 in approving the follow-on mission. What difficulties there were lay elsewhere.

Reactivation II

The spacecraft was now further from the Sun, and would be much colder in hibernation than before (Fig. 5). Reactivation of the spacecraft could only occur after solar-array power levels had risen above the minimum needed for spacecraft operation at S-band. This would not take place before May 1992, only 2.5 months before the day of encounter.

Plans for this second reactivation were laid, and once again the NASA DSN generously offered to provide support. At reactivation in 1992, the spacecraft–Earth range was 219 million kilometres, more than double what it had been in 1990. This meant that the signal received from the LGA would be at the limit of detectability, even using a 70 m DSN antenna, and it was doubtful whether the Doppler data in the downlink, so valuable in 1990, would be discernible.

Whilst taking advantage of the experience gained in 1990, the reactivation strategy had to account for the possibility that Doppler would not be available. The strategy was, however, to a certain extent simpler as the units known to have failed in 1990 did not need to be added to the list of units to be selected. Additionally, knowledge of the spacecraft's attitude after entering Hibernation II provided a much improved estimate of the likely attitude at reactivation.

At 14:08 GMT on 4 May 1992, the DSN once again swung the Madrid antenna towards Giotto, and after 2 h reported ground receivers in lock at an amazing −171.5 dBm. Fortunately, Doppler data was detectable, and showed a nominal orbit and a nominal spin rate of 14.93 rpm – Giotto was still out there!

A test to activate the despin mechanism resulted in the expected 0.1 rpm increase in spin rate and showed that the spacecraft units selected for the reactivation process were functional. In view of the limited power available, the despin had to be switched off again, as well as all heaters, before manoeuvres could be started. As in 1990, successful manoeuvre execution was evident from Doppler data. To avoid cooling the spacecraft too much, manoeuvres were to be divided into sequences lasting no longer than 70 min each, interspersed with periods assigned to heating.

At 01:54 GMT on 7 May, reactivation was essentially complete, with a steady downlink available from the spacecraft HGA. Telemetry data processing was at first hindered by a problem in a telemetry pre-processor at ESOC, remedied by mid-afternoon on the same day. The spacecraft was declared fully reactivated after successful attitude determination had been performed using star-mapper data.

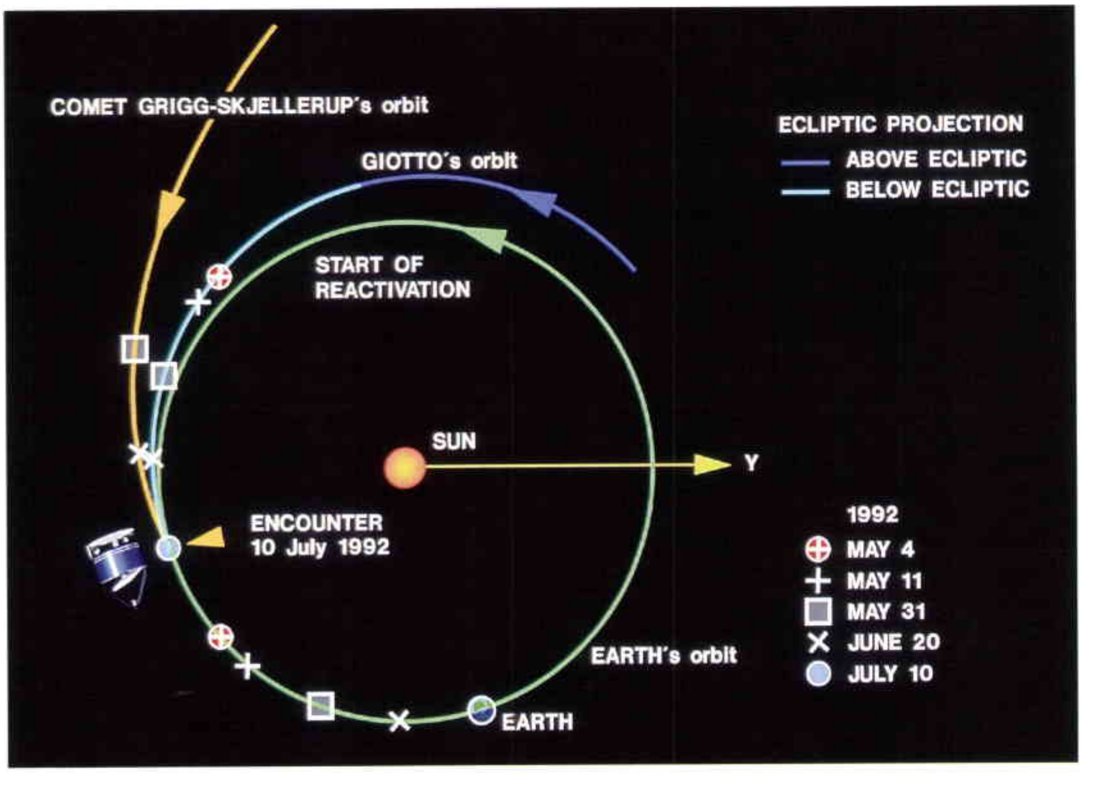


Figure 5. The orbits of Giotto, the Earth, and Comet Grigg-Skjellerup in 1992

An assessment of the spacecraft's health showed no further degradation since 1990, although the solar-array output was some 3% below predictions.

Cruise operations

An attitude strategy had been established to maximise solar-array output at all times, while permitting contact via the HGA. The array power available would not reach the level needed to support X-band operations until after 1 July 1992 (Fig. 6), only 10 days before encounter, and the power margin predicted for the day of the encounter was of the order of 14 W, sufficient for a minimum complement of experiments with no margins. There was a keen interest in performing tests on the batteries, which had been out of service since 1986.

The silver-cadmium batteries onboard Giotto, although never really used, had been in space for nearly 7 yr, and had been subjected to thermal cycling up to temperatures of 50°C during Hibernation I. A series of tests were performed to investigate the health in charging and discharge of each battery in turn. The tests proved successful in that there was useful life left in three of the four batteries, albeit a small fraction of the original capacity. While not allowing additional loads to be introduced, the batteries would provide some degree of buffering against power spikes and, as their discharge characteristics were now known, they would provide an early indication of any potential power problem at encounter.

Checkout of the experiments had been foreseen to start when X-band operations could be supported. This left little time before the encounter, however, and so a plan to start checkout at S-band at 5.7 kbit/s was introduced. The DSN stations were the only ones able to receive Giotto telemetry at S-band: Perth and Weilheim were available for commanding, but would only be available for telemetry once X-band operations started, and then for nothing more than 360 bit/s. There was no opportunity to perform encounter rehearsals on this mission. In the meantime, the question of targetting needed attention, for this time there was no 'Pathfinder' and no Vega mission.

Targetting for Comet Grigg-Skjellerup

Grigg-Skjellerup is an old inactive comet, with a dust and gas production rate of the order of 0.75% of that of Comet Halley and an orbital period of about 5 yr. Observed a total of 142 times in the period between 1977 and 1989, it was expected to become observable with large telescopes late in 1991. In an unprecedented move, ESOC called upon the good will of the astronomy community to undertake a comet observation campaign. With the data collected, it was possible to reduce the uncertainty in knowledge of the comet's position from 3000 km before reactivation, to less than 650 km (Fig. 7).

Two orbit-control manoeuvres were performed: the first on 22 May, when 1 kg of fuel was used to impart a delta-V of 3.5 m/s over a period of 90 min, reducing the predicted flyby distance from 167 400 km to 510 km.

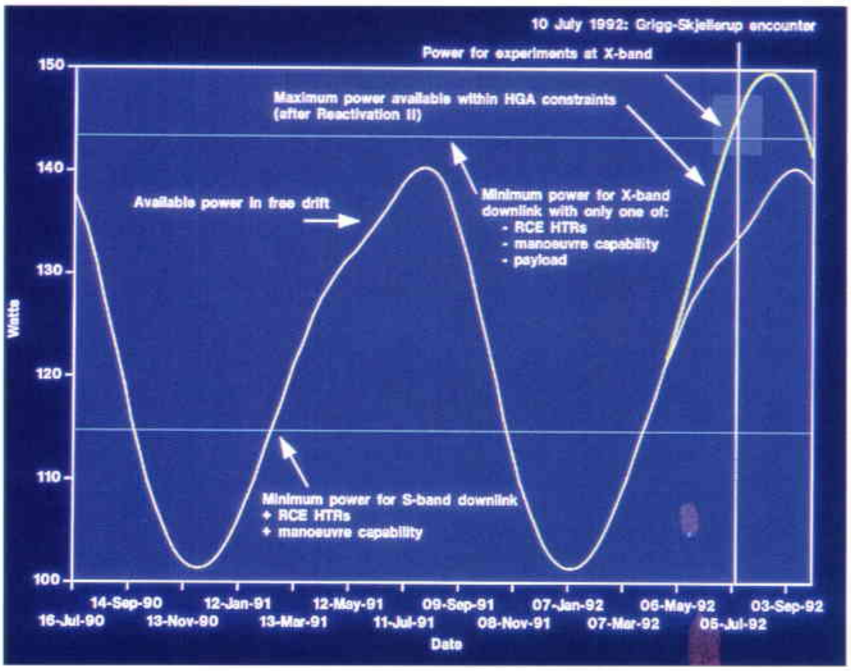


Figure 6. Giotto's power availability approaching the Grigg-Skjellerup encounter

The final manoeuvre was performed on 8 July, when 0.6 kg of fuel was used to impart an additional 2 m/s to the spacecraft's velocity over a period of 53 min, reducing the flyby distance to near zero. Great care was also needed in adhering to the attitude strategy, particularly with respect to timing, as each attitude manoeuvre had an influence on the final targetting.

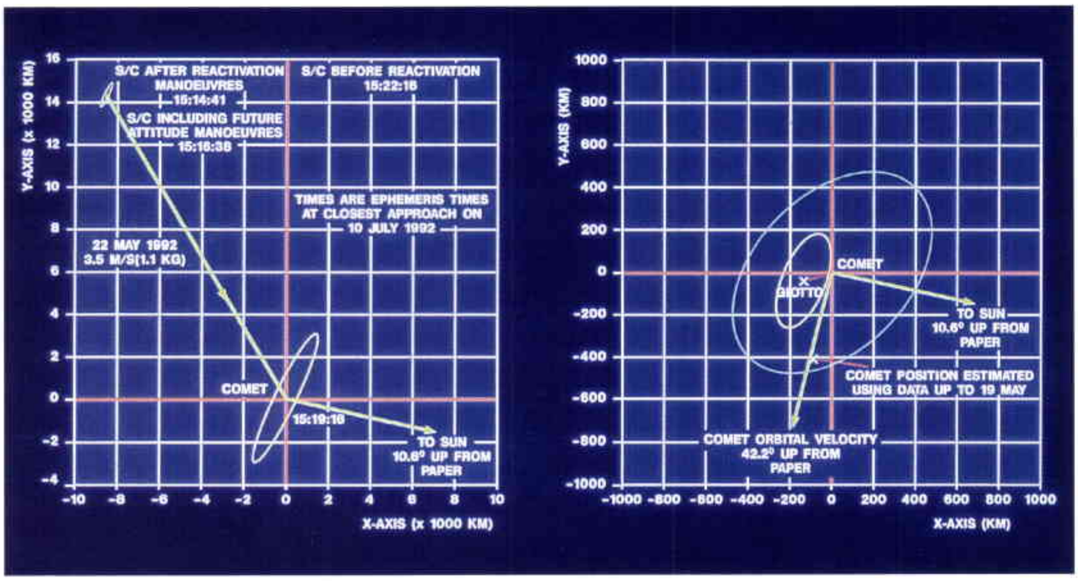
Pre-encounter preparations

Between 8 June and 8 July, all experiments known to be functional in 1990 were checked out. The Camera was once again tested, but no change in status was found. The encounter configuration was defined, with the severe restrictions in available power in mind. This meant, in particular, that:

- all heaters would have to be switched off
- the redundant TWT could not be used in warm standby
- no commanding would be permitted during the encounter except for

Figure 7a. Predicted spacecraft positions (with 3 σ ellipses) in the target plane using data up to 19 May 1992

Figure 7b. Predicted spacecraft positions (with 3 σ ellipses) in the target plane using data up to 7 July 1992



spacecraft emergencies, most notably in the event of loss of downlink, and

- to provide an additional power margin, there would be no uplink from the ground.

In view of the known failures onboard, there was no redundancy in:

- the service converter supplying the despin and AOCS
- the despin electronics, as a consequence of the above
- the data-handling CTU (a switch-over of the data-handling converter would have led to a loss of telemetry as a result).

Encounter operations started some 24 h before closest approach, scheduled for 15:30:36 GMT on 10 July. The Magnetometer and Energetic-Particle Analyser had been on for some time prior to the start of the phase, when at 15:49 on 9 July the downlink was configured to 46 kbit/s at X-band, using the DLR Weilheim station. A set of time-tag commands were loaded for the desired experiment mode changes during the encounter, and the next set of experiments including the Rème Plamsa Analyser (by now considered to be safe), and the Ion Mass-Spectrometer. The remaining experiments, including the Johnstone Plasma Analyser, the Optical-Probe Experiment and the Dust-Impact Detector, were to be switched on by time-tag after removal of the uplink, as part of the power-conscious approach.

Round-the-clock telemetry coverage was provided by stations of the DSN, although an earthquake in California had put the Goldstone 70 m station out of action, and it had to be replaced at short notice by two 34 m antennas in array.

The spacecraft had been configured for encounter, entailing switching off all heaters, enabling the Battery Discharge Regulators, and disabling the Reaction Control System. At 18:05 on 9 July, the uplink from Weilheim was removed, and the spacecraft was on its own, unless something serious went wrong.

The Grigg-Skjellerup encounter

There were a number of features of the Comet Grigg-Skjellerup encounter that were most unlike those at encounter with Halley:

- The spacecraft–Sun–Earth geometry at encounter in July 1992 meant that Grigg-Skjellerup would approach Giotto at an angle of 68°, instead of head-on as at Halley: hence the bumper shield would afford no protection.
- The relative velocity was 14 km/s, with the comet meeting Giotto from below and behind, whereas Halley had met Giotto head-on at 68 km/s.
- The Earth range at encounter was 214 million kilometres, leading to a round-trip light time of 24 min. At Halley, the range had been 140 million kilometres and the light time 16 min.

Although Comet Grigg-Skjellerup was significantly less active than Halley, there was real concern that Giotto would be damaged due to the angle of attack. Also of concern was the time that the ground would take to respond to anomalies no longer recoverable by autonomous actions on board, especially without an uplink ready.

As it turned out, the encounter phase went without a hitch, providing experimenters with their second opportunity to fly by a comet. The science data processed in real time at ESOC provided immediate access to the cometary environment with the first evidence of cometary ions detected when more than 600 000 km from the comet. While the Magnetometer and Plasma and Particle Analysers were measuring activity over a long period, evidence of cometary dust was first reported by the Optical Probe 10 min before closest approach, which appeared to occur at 15:30:40 GMT when DSN Madrid reported a momentary loss of synchronisation. At 15:30:56, the Dust-Impact Detector reported the first of three impacts, also shown by evidence of spacecraft nutation (±0.1°) and a very small increase in spin rate (+0.003 rpm). Thereafter, measurements were made on the outward journey until 03:00 on 11 July, when all experiments were switched off.

The spacecraft had apparently come through unscathed.

Post-encounter status

The power drawn by the experiments during the encounter turned out to be less than predicted, with telemetry indicating 11.5 W against the 15 W predicted. There was a steady 10 W available in the shunt, a safe 3 W above the level at which the batteries were expected to discharge, and no solar-array degradation was observed.

Spacecraft temperatures were satisfactory, with hydrazine lines stabilised at 4.5°C: heaters were switched back on after experiment switch-off.

The TWT performed faultlessly throughout encounter.

On the morning of 11 July, it was discovered that Decoder 1 was no longer operational, having processed some 197 704 commands since 1985 without difficulty. Decoder 2, which provides full redundancy, processed about 5000 commands in the same time period.

Hibernation III

After all pre-encounter manoeuvres had been performed, there was still 15 kg of fuel remaining. It was concluded that, allowing for the ±3 kg uncertainty in fuel book-keeping, there was sufficient available to perform an orbit manoeuvre that would put Giotto on another Earth-swingby trajectory in July 1999. There would not be sufficient fuel for a further cometary encounter, although possible targets in 2005 and 2006 had been investigated.

Final orbit manoeuvres were performed on 21 July, when a delta-V of 33 m/s was imparted to Giotto in a burn lasting 4 h, and on 23 July, when a final correction based on Doppler data was made, imparting 3 m/s over a period of 20 min.

After completion of the orbit manoeuvre on 23 July, the spacecraft was put into hibernation for the third time. Care has been taken to preserve the spacecraft as much as possible, by providing the maximum heating power compatible with the power constraints, and by employing the same configuration and by placing the spacecraft at a similar attitude as had proved successful in 1990.

The final trajectory is expected to bring Giotto to within 219 000 km of Earth on 1 July at 02:40:26 GMT. A simplified reactivation opportunity will occur early in 1999 when, at about 20 million kilometres from Earth, the spacecraft will pass through a phase in which the Earth aspect angle is naturally 44.2°. It is, however, unlikely that Giotto will be reawakened!

Conclusion

In 1986, the Giotto Operations Team were pessimistic about the feasibility of entering into a further mission scenario, as the spacecraft was suddenly bereft of all autonomous provisions for Earth recovery. This feeling was not helped by the loss of redundancy as a result of the first period of Hibernation, when Giotto had been exposed to high extremes of temperature. The extremely low power margin predicted for the Grigg-Skjellerup encounter was also very worrying. The fact that Giotto has now passed close to two comets, has been hibernated three times, and reactivated twice, as well as performing an Earth swingby, is a tribute not only to the quality of the spacecraft design and build, but also to the dedication of all concerned in the preparation and execution of spacecraft and ground operations during both missions.

It should also be remembered that, without the unfailing support provided by NASA's DSN and JPL, the 'razor-edge' Giotto Extended Mission would not have been possible.

The latest analysis by the Optical-Probe Experiment Team suggests that Giotto flew within 200 km of Comet Grigg-Skjellerup, at a distance of 214 million kilometres from Earth.

The Ariane-5 launcher. Inset, the dynamic mockup of the H155 stage. (Photo courtesy of Aérospatiale)

Ariane-5: The H155 Cryogenic Main Stage

P. Guillard
H155 Programme Manager, Aérospatiale, Les Mureaux, France

H. de Boisheraud
Deputy Ariane-5 Programme Manager, ESA, Paris

Introduction
Despite its name, Ariane-5 is in fact a completely new launcher that will increase European competitiveness in the field of commercial launches and ensure that Europe has autonomy for the new missions that are taking shape. The commercial missions planned for the end of the century will use the same orbits as those used today: geostationary, Sun-synchronous, and low orbits and trajectories for space probes. These new missions foresee the existence of both inhabited stations and multi-mission platforms.

Studies on the foreseeable trend in the launch market have shown that the masses of payloads to be placed in orbit will continue to increase, as will the number of applications requiring low Earth orbits. In addition, the pressure to compete makes it necessary to improve reliability and reduce launch costs. For its own in-orbit experiments, Europe must also have the means necessary for accessing a Space Station and transporting both crews and equipment. It was against this background that the European Ministers, meeting in The Hague in November 1987, decided to commit to the development of the Ariane-5 launcher.

Ariane-5 is perfectly equipped to meet all of these requirements as a result of its novel and simple design, consisting of a lower composite that stays the same for all missions and an upper composite that is tailor-made for each individual mission.

The lower composite, which provides most of the launcher's thrust, consists of two large solid boosters, each loaded with 230 t of propellant, attached to the sides of the H155 cryogenic main stage. The development of this stage, which is over 30 m high, has been entrusted to Aérospatiale, which subcontracts work to a large number of European firms.

The development studies and tests that started back in 1987 are now extremely well advanced and the photographs in this article show that the H155 programme is progressing smoothly.

Stage definition
The stage's general architecture and definition are the outcome of systematic studies of the concept and technology choices for each subsystem in the light of the functional and economic performance objectives assigned for the stage (Figs. 1 & 2).

As shown in Figure 3, the H155 stage consists of:
– a forward skirt that transmits the thrust of the two P230 boosters and the Vulcain engine to the upper composite; in addition, the skirt houses pyrotechnic equipment and onboard electrical equipment such as the power supply, communications, flight control, sequencing, telemetry, tracking and safety systems;
– cryogenic tanks with a common bulkhead, which store the propellant required for powered flight and transmit loads from the lower part of the stage;
– a thrust frame that:
  - has attachments for the lower end of the P230 boosters
  - transmits the thrust of the Vulcain engine
  - houses all the equipment required for powered flight (propellant feed system, cryogenic valve command system, tank pressurisation systems and POGO control system); the equipment providing a fluids interface with the ground is also attached to the thrust frame;
– a Vulcain engine.

The joints between the principal structures are bolted between the thrust frame and the tanks and riveted between the tanks and the forward skirt.

The stage's main technical and performance characteristics are summarised in Figure 4.

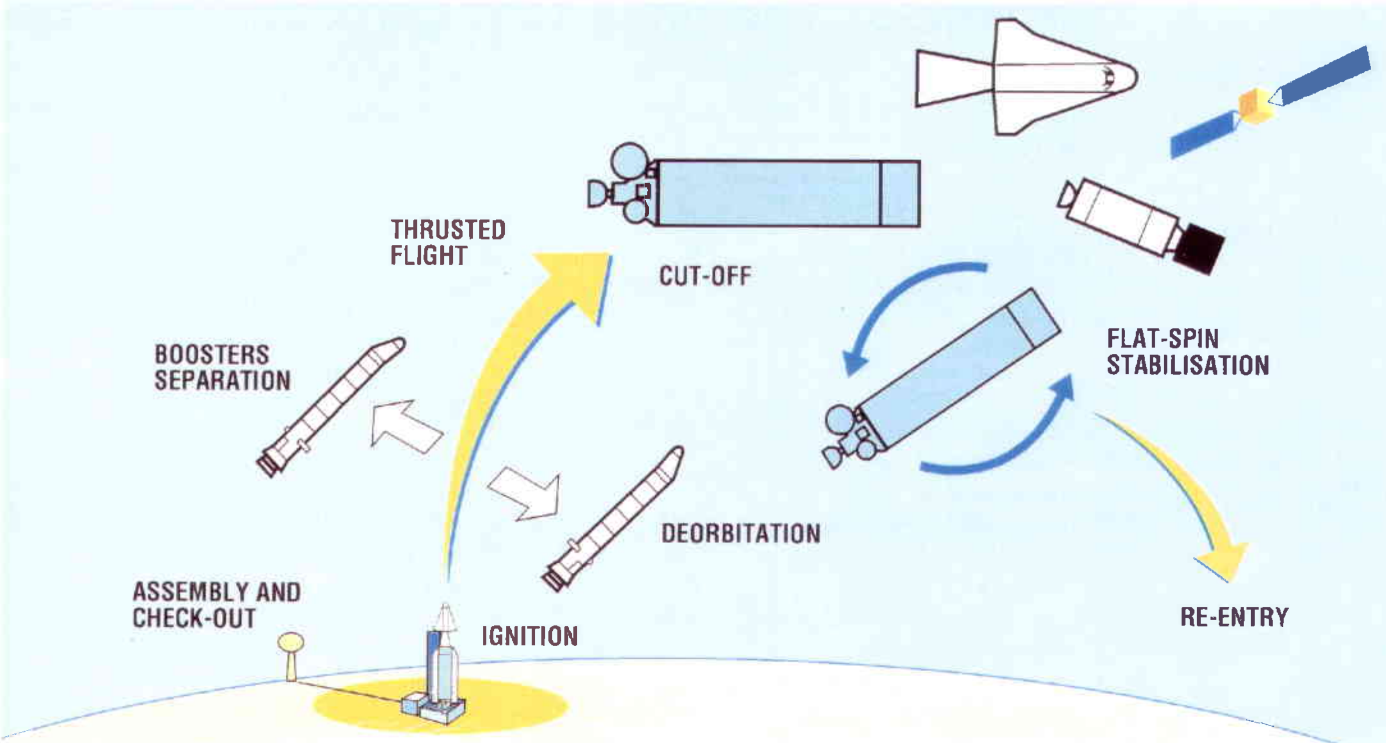


Figure 1. The H155 stage's operating scenario

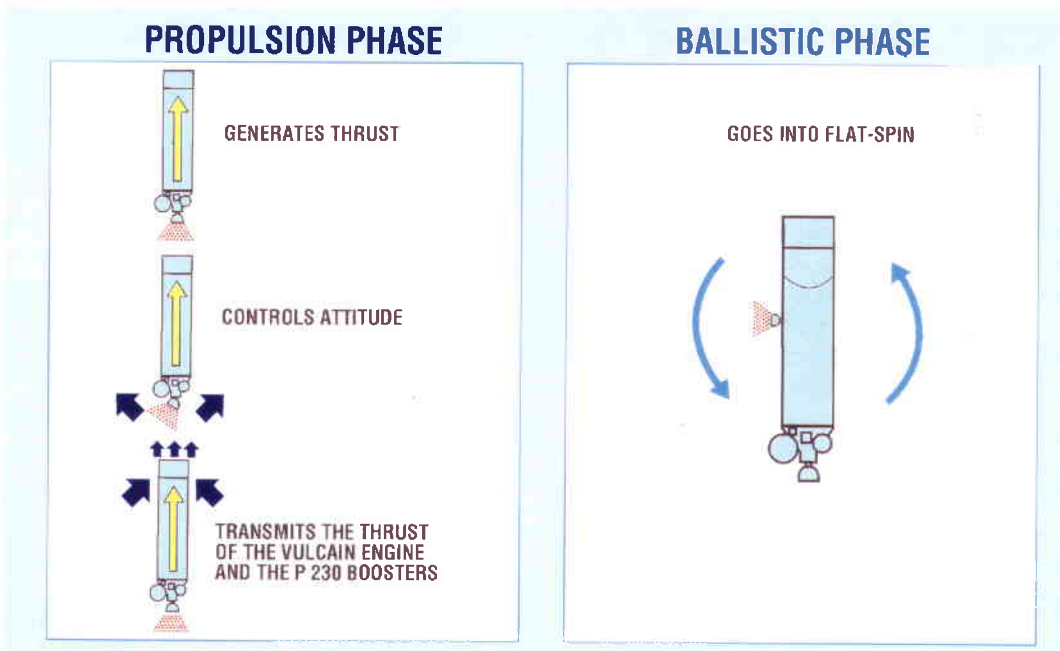


Figure 2. The H155's main functions

LENGTH	30,5 M
DIAMETER	5,4 M
THRUST	1120 KN
SPECIFIC IMPULSE	430 S
THRUST DURATION	10 MINUTES
PROPELLANT MASS	156,2 T
• liquid oxygen (-183° C)	130,6 T
• liquid hydrogen (-250° C)	25,6 T
STAGE DRY MASS	12,4 T

ENGINE SWIVELLING MAX.ANGLE	6°
ANGULAR VELOCITY	15°/s
POWER SUPPLY STORAGE	
PNEUMATIC (He) :	30 kg/300 bars
HYDRAULIC (F2H) :	55 kg/220 bars
LIQUID HELIUM (-269° C) :	140 kg/ 25 bars
ELECTRICAL POWER	2,5 KVA

Figure 4. The main characteristics of the H155 stage

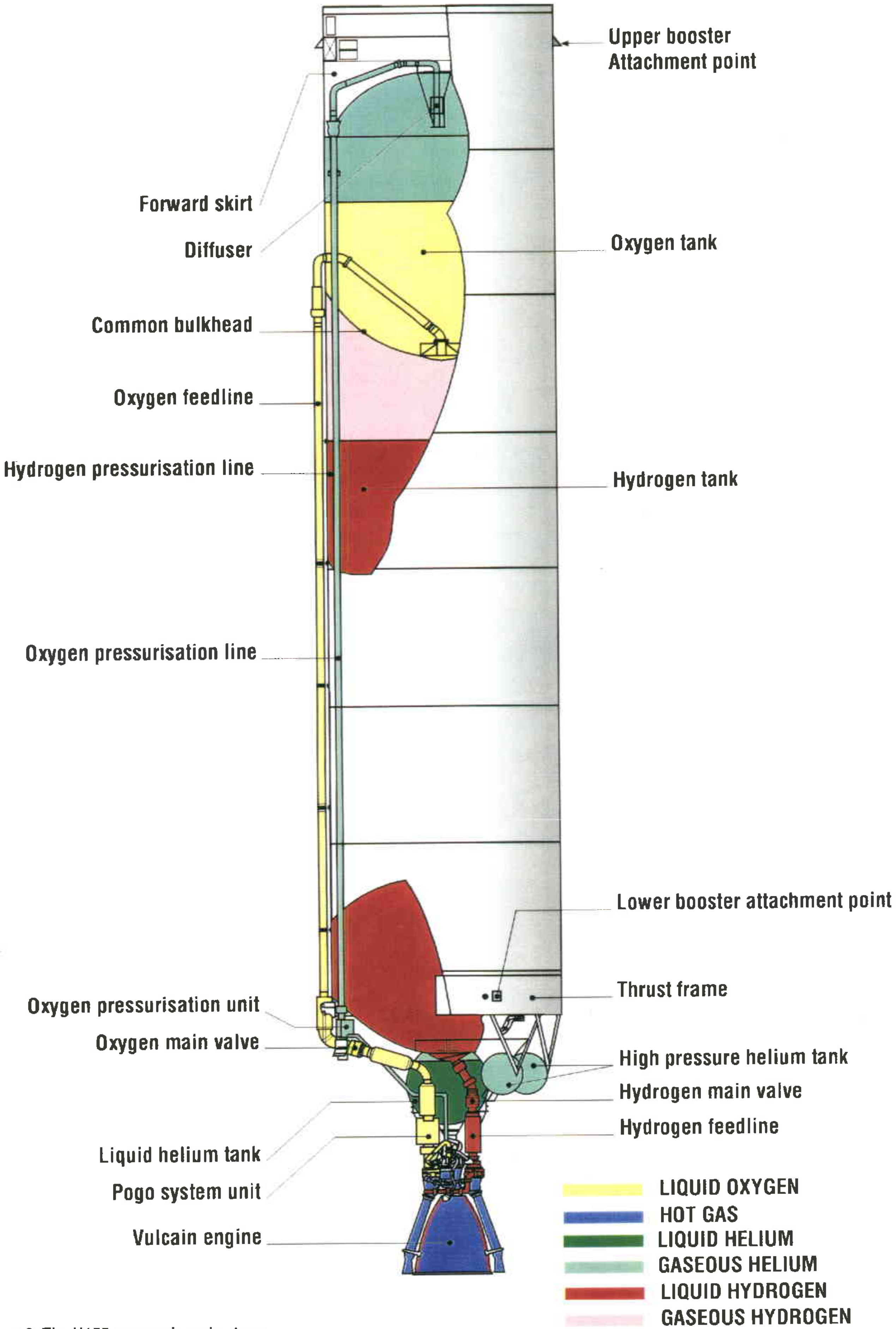


Figure 3. The H155 cryogenic main stage

General operation of the stage

Ground phase

Most of the operations in preparation for the launch of the H155 stage are performed in the rear zone of the third Ariane launch site (ELA-3) at the Guiana Space Centre. This launch site has been purpose-built for Ariane-5.

Following transfer of the launcher to the launch zone, i.e. 12 h before lift-off, the large cryogenic tanks are filled simultaneously with propellant – 131 t of liquid oxygen and 25 t of liquid hydrogen – in under three hours. The final launcher activation operations up to lift-off are carried out using an automated command and control sequence which, in the case of the H155, mainly concerns:

- isolation of the stage from the ground as regards fluids (except for flushing of equipment for conditioning purposes)
- propellant tank pressurisation to flight level
- flight configuration of the stage fluids and electrical systems
- the Vulcain engine start-up sequence, on which authorisation for igniting the two solid boosters depends.

Initial integration of the aft part of the H155 stage. In the foreground is the liquid-helium storage sphere and on the left (black in colour) are the storage spheres for the gaseous helium (at 400 bar pressure), which feed the command system at 70 bar (Photo courtesy of Aérospatiale)

In the event of one of the engine-monitoring logic criteria not being observed, an engine shutdown command is issued immediately and is followed by a series of operations restoring the stage (and launcher) to the necessary state of safety before proceeding to empty the tanks.

Powered-flight phase

Ignition of the solid boosters initiates the lift-off. In contrast to the method adopted for the third stage of Ariane-4, in which the cryogenic-fluid lines are disconnected prior to ignition of the first-stage engines, the H155 setup exploits the launcher's initial movement to trigger a mechanical separation device that releases the cryogenic-fluid lines located at the rear of the stage.

Throughout flight, the hydrogen tank pressure is regulated by an 'all or nothing' supply of hydrogen gas taken from the outlet of the engine's regenerative circuit. In addition, the oxygen tank pressure is regulated by an 'all or nothing' supply of helium gas stored in liquid form in a dual-walled spherical tank (containing 140 kg of liquid helium at a temperature of about 270°C) and heated to −30°C by the engine. The choice of this design was dictated mainly by the reliability, availability, maintainability and safety criteria for crewed flights.

A gaseous-helium circuit pressurised to 70 bar is used to:

- control the cryogenic valves
- pressurise the liquid-helium tank via an 'all or nothing' supply
- operate the POGO control system.

The stage helps to control the launcher's attitude via an engine actuation unit comprising two servo-actuators, each delivering about 100 kN. These servo-actuators are fed using the lost-oil hydraulic-generation method, operating in blowdown mode between 220 and 150 bar.

On an automatic mission, launcher roll during the H155 powered-flight phase is controlled by the attitude-control system in the Vehicle Equipment Bay located just above the stage.

At the end of the powered-flight phase, the engine shutdown command is triggered by the on-board computer once:

- the launcher is flying at the requisite speed, and
- a critical level of depletion of one of the two propellants is reached.

Ballistic-flight phase

Because of its duration, the ballistic trajectory followed by the stage after it separates from the launcher calls for a special 'passivation' and attitude-control procedure in order to meet safety requirements for the territories on the flight path. This procedure involves putting the stage into a rapid flat spin, thereby providing the correct attitude for re-entry. This is achieved by issuing a pyrotechnic command which opens a lateral vent hole in the hydrogen tank to provide the necessary momentum.

To achieve complete 'passivation' of the stage, a similar command is given slightly later to remove the gas from the oxygen tank, keeping the bulkhead common to both tanks structurally intact.

By applying this procedure, the H155 stage will splash down about 200 km off the coast of South America.

The cryogenic tank

This structure, built by Cryospace, contains a total of 157 t of propellant: a tank in its upper part holds 131 t of liquid oxygen, and another in its lower part holds 26 t of liquid hydrogen. These tanks, which are made of aluminium alloy 2219 and are thermally insulated by adhesive insulating panels, are 23.8 m high and 5.4 m in diameter.

The oxygen tank has:

- two hemispherical domes made of aluminium alloy, which have a radius of 3 m and are 2 mm thick; the oxygen tank's lower dome is shared between the oxygen and hydrogen tanks
- two cylindrical sections 5.4 m in diameter and with a nominal thickness of 4 mm, each section being made by welding together three machined and formed aluminium panels.

The hydrogen tank has:

- a hemispherical lower dome, which has a radius of 3 m and is 1.6 mm thick, and six basic cylindrical sections, 2 mm thick.

The insulating material protecting the cylindrical sections and the upper and lower domes is the same as has been used for 10 years on the Ariane-1 through 4 cryogenic tanks.

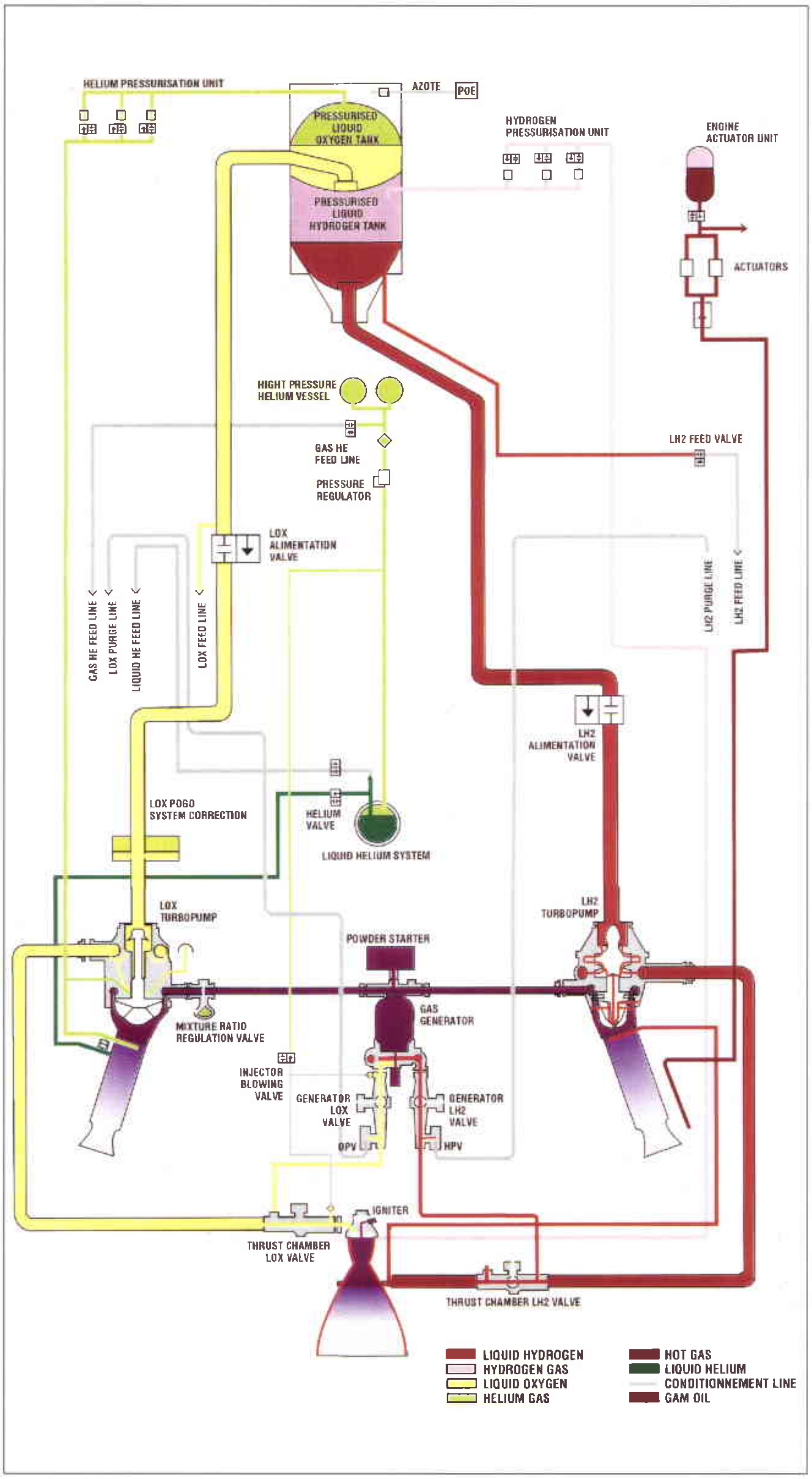
The remainder of the tank is made up of a series of internal and external items of equipment, in particular:

- pipework carrying propellant and tank-pressurisation gases to and from the engine
- gas diffusers, and anti-vortex and anti-sloshing devices
- measuring instruments providing the onboard computer with data on liquid and gas pressures, temperatures and levels.

The industrial setup

The prime contractorship for building the tank was awarded to Cryospace (an economic-interest grouping consisting of L'Air

The H155 stage hydraulics




The H155 stage cryogenic tank (Photo courtesy of Cryospace)

Liquide and Aérospatiale, with holdings of 55% and 45%, respectively), which has allocated responsibilities to the following firms:
- Dornier (Germany) for the hemi-spherical domes
- Aérospatiale (France) for the cylindrical-section panels
- MBB (Germany), SDP (Austria) and Idrosapiens (Italy) for the valves, small pipework and bellow expansion/contraction joints for the lines.

The unusual dimensions of the tank led Cryospace to site its new production plant at Les Mureaux (F). In deciding to adjoin it to the stage integration building, which itself stands on the banks of the River Seine, Air Liquide and Aérospatiale have provided an integrated plant in which subassemblies and basic components enter through one door and complete stages destined for the Kourou launch site go out through another.

All the operations for welding the cylindrical sections and the domes (which are themselves delivered welded) are performed in this building, which covers an area of 15 000 m^2 and is over 41 m high in the erection zone. There are also specialised units for carrying out delicate operations such as degreasing, fitting of thermal insulation, painting and integrating various items of equipment.

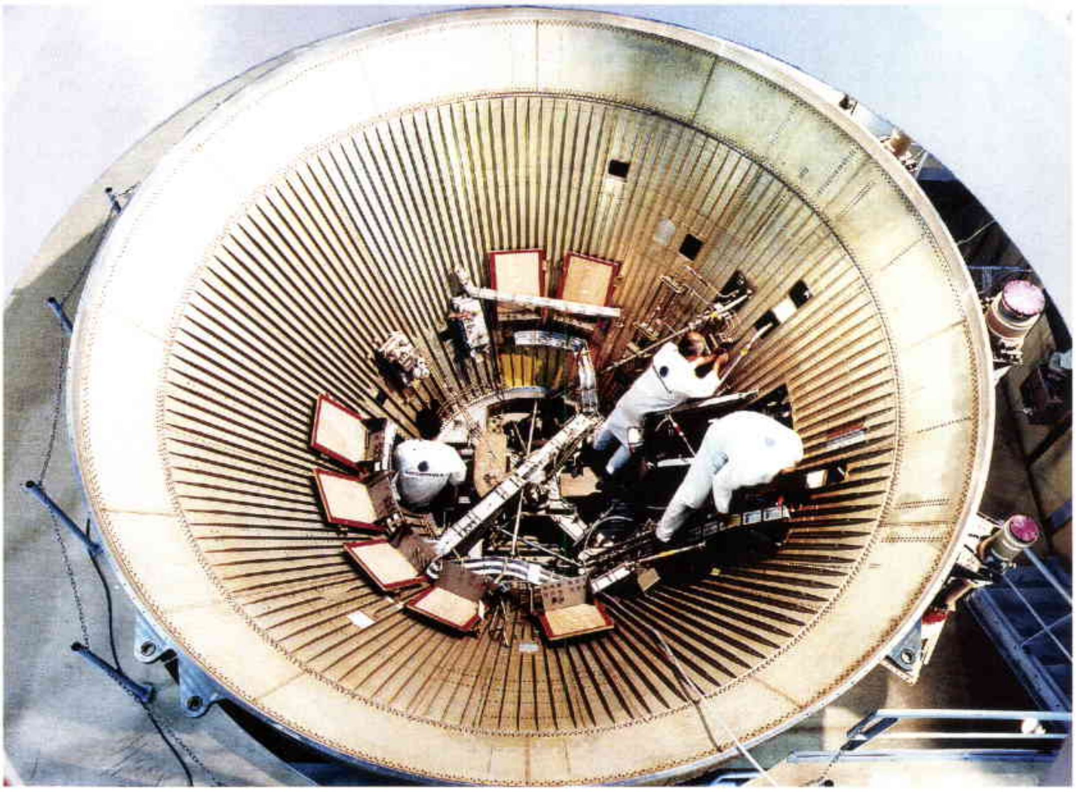
There are also two other especially impressive facilities:
- the welding bench with an overall length of almost 45 m, and
- the proof-pressure pit, which is 9 m in diameter and 30 m deep and is sealed by a concrete cover weighing over 280 t.

The first tank was delivered by Cryospace in September 1992 and is currently being used in the H155 dynamic-mockup exercise. A second tank is nearing completion and the third one, to be used for qualification, is now being welded.

The forward skirt

MAN (D) is responsible for developing this structure, the main features of which are as follows:
- diameter: 5.4 m
- height: 3.3 m
- mass: 1800 kg
- material: mostly aluminium alloy 7075.

This structure is of a sound, well-optimised design and consists of:



The H155 stage thrust frame being fitted with equipment (Photo courtesy of Aérospatiale)

- a cylindrical section obtained by assembling six basic panels that are pleat-stiffened and thermo-formed (creep-forming)
- a ring structure partly fitted with an internal carbon sandwich skin and providing the rigidity required for the P230 attachments
- a forward flange with recessed bolts, providing a mechanical connection with the upper composite
- side fittings for attaching the P230s.

The stage's electrical equipment is accommodated on carrier platforms fixed to the ring structure. For reasons of redundancy and in order to limit the effects of pyrotechnic shocks produced by the stage separation systems, these platforms are distributed between two symmetrical zones lying at right angles to the plane of attachment for the P230 boosters.

Three development units of this skirt have already been delivered, including the qualification unit, which has been undergoing tests since November 1992. The Qualification Board is due to meet in late 1993.

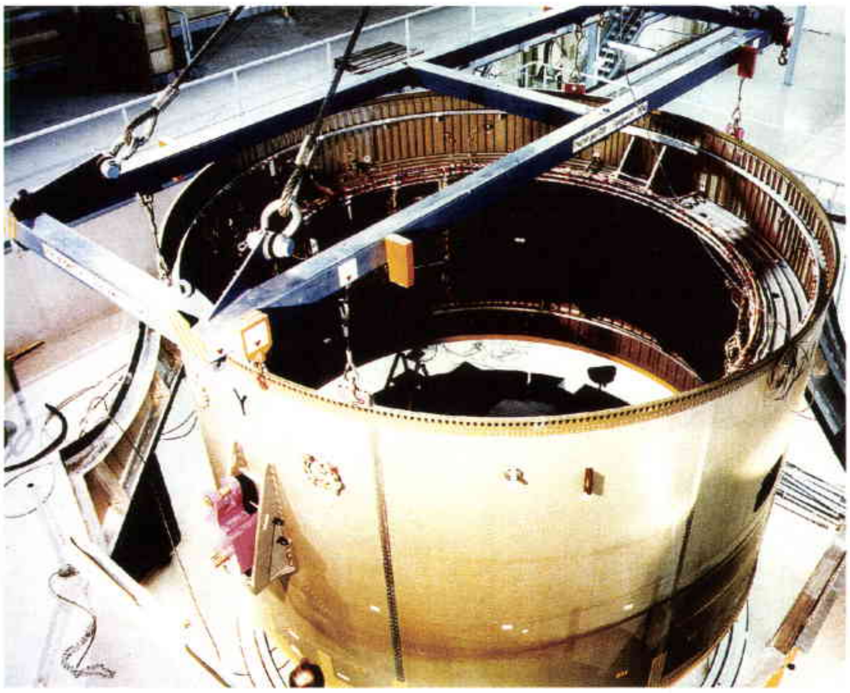
The thrust frame

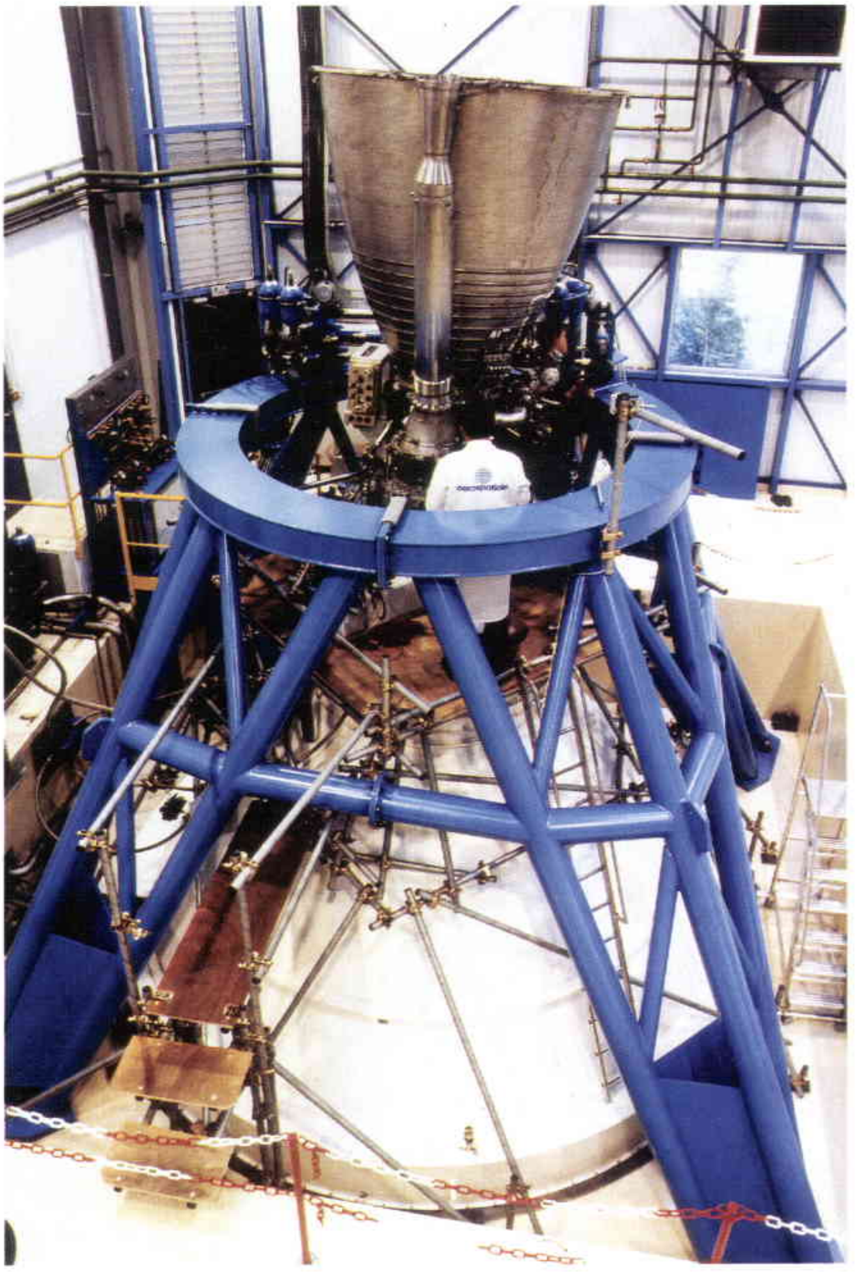
The thrust frame, which is made of aluminium alloy 7075, has a mass of 1700 kg and a height of 3.5 m. It is built by Fokker Space Systems (NL). This structure, which is fairly complex because of its many interfaces, consists primarily of:

- a ring structure in the upper part, providing the mechanical connections with the hydrogen tank and the P230 aft attachment devices
- a truncated cone of eight pleat-stiffened panels made by peen-forming
- a cross-shaped structure for attaching the engine and actuators.

Optimisation criteria for the thrust-frame architecture have meant distributing the

The H155 stage forward skirt prior to its delivery (Photo courtesy of Aérospatiale)





equipment between the inside and outside of this structure. Four development units have already been produced, including the unit to be used for the hot tests on the 'battleship' stage in Kourou in January 1994.

Qualification of the thrust frame is due to take place in 1994.

Development status of the stage

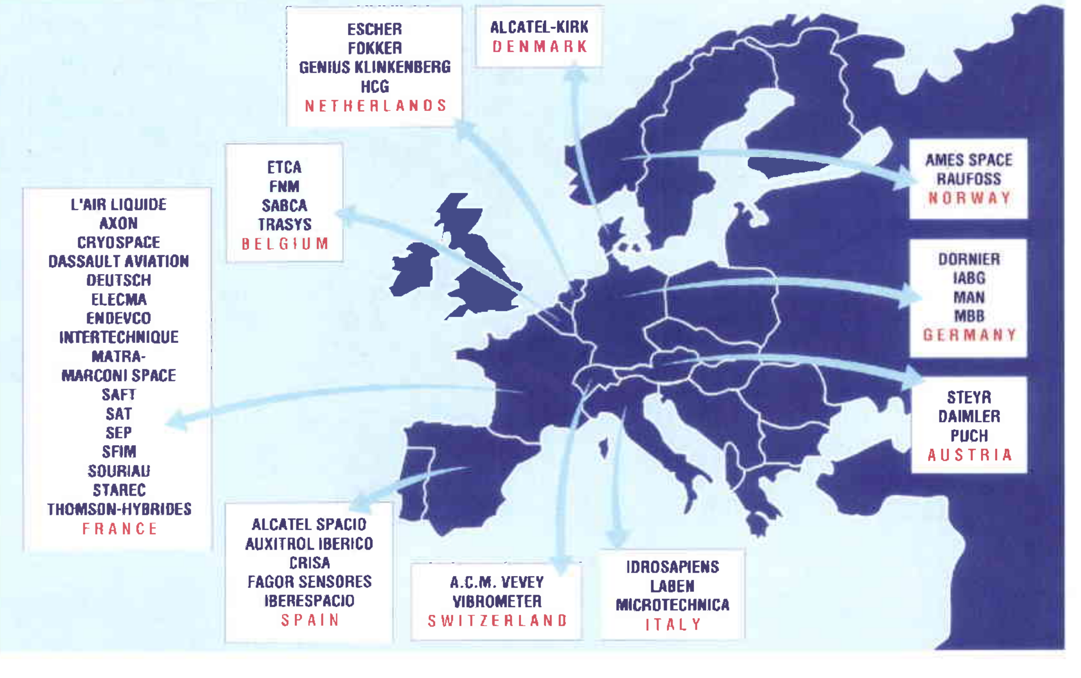
Under the programme's industrial organisation, Aérospatiale, prime contractor for the H155 cryogenic main stage, is responsible for development of the stage as a whole, in cooperation with:
- SEP, which is prime contractor for propulsion and the Vulcain engine, and
- over forty European firms with responsibility at various levels for the development of the component elements and the operating and test facilities.

As part of its responsibilities as prime contractor, Aérospatiale conducts a series of tests which, following the progressive integration of the component parts, leads to ground qualification of the stage and validation of the industrial operations.

Development testing

The development tests are performed directly on the complete stage or part of it, or accompany system-level testing. Of the many tests carried out, the following are the most significant:
- flight-control mockup tests, the objectives of which are to characterise, adjust and validate the redundancy logic of the servo-actuator loop; these tests took place successfully from February to August 1992;

The H155 stage flight-control mockup; inside the blue structure is the Vulcain engine mounted on the thrust frame (in white) (Photo courtesy of Aérospatiale)



Geographical distribution of industrial participation in the H155 programme

- vibration and pyrotechnic shock tests on the forward and aft parts of the stage, which lead to validation of the layout and mechanical environments required for the equipment; they were performed on the forward part of the stage during the first quarter of 1992 and broadly confirmed the definition; they have been continuing on the aft part since October 1992;
- electrical tests on the stage functional reference mockup have been under way since October 1992 for the forward part and end in late 1993 with the electro-magnetic-compatibility tests;
- acoustic-environment compatibility tests on the forward and aft parts are scheduled for 1994;
- functional integration tests on the engine feed and actuation equipment, performed as accompanying objectives during engine tests, have been in progress since early 1993;
- lastly, two campaigns of hot tests are planned, consisting of: tests, scheduled for late 1993, on the aft part of the stage, which is mated with heavy tanks to form the H155 'battleship' stage; and 'M' tests that will complete the development phase in the stage's functional integration, due to take place in the second half of 1994.

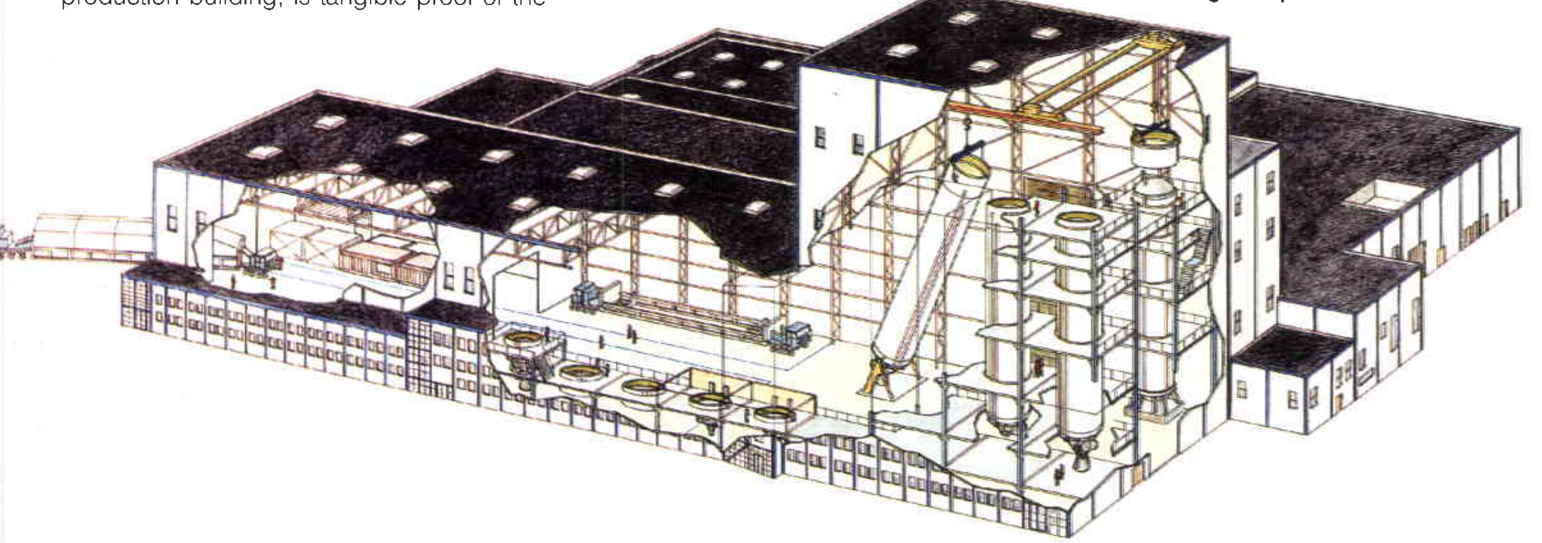
The qualification tests also take place in two phases:
- hot tests on the complete stage, the objective being to validate the qualification configuration of the stage and the associated software
- in-flight stage qualification tests during the first two Ariane-5 launches.

The production process
The Ariane-5 Integration Building, which is situated on the banks of the River Seine at Aérospatiale's premises in Les Mureaux (F), and which adjoins Cryospace's tank-production building, is tangible proof of the way in which the stage's industrial production process involving manufacture, integration and transport has been optimised.

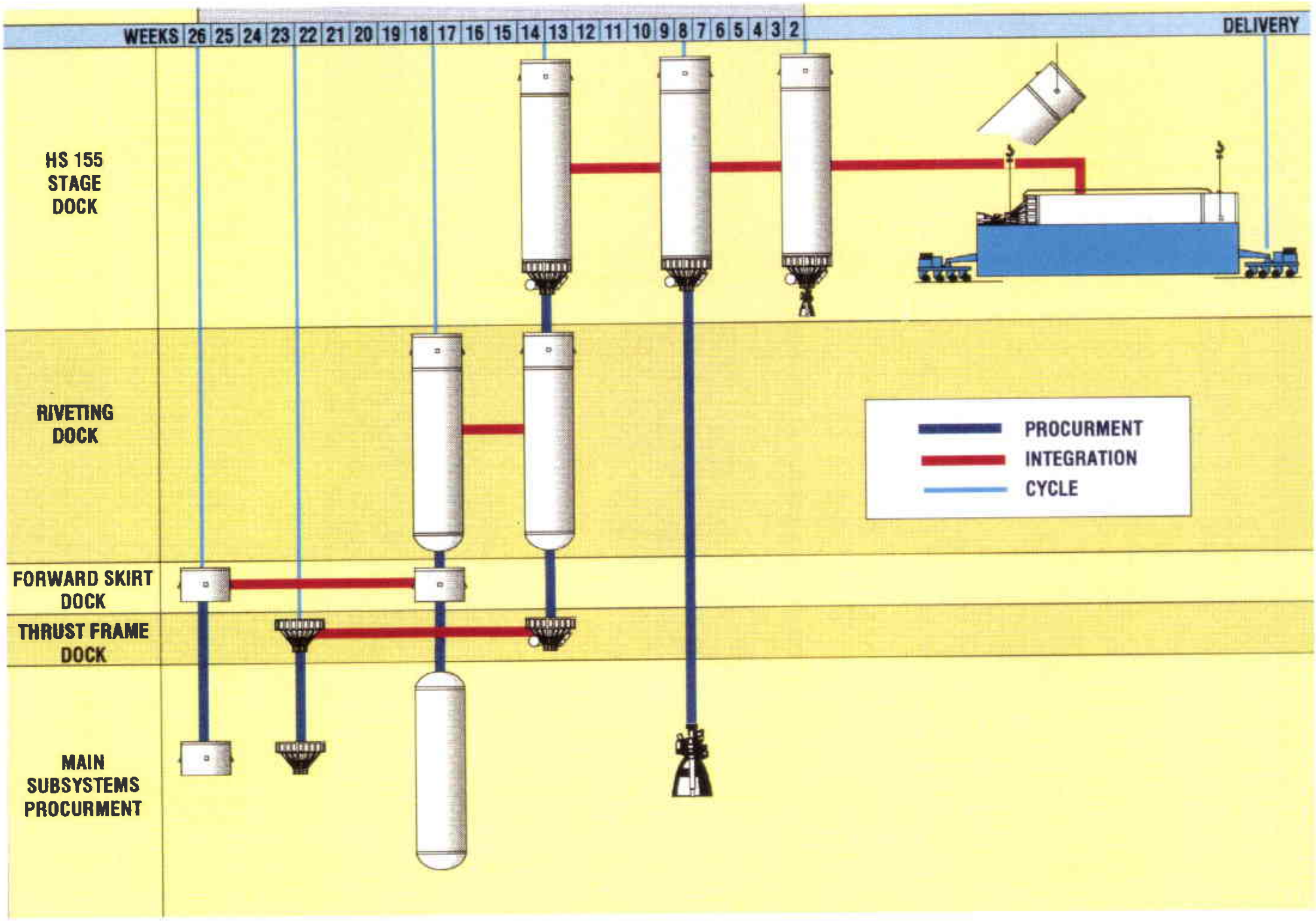
Vibration unit of the aft part of the H155 stage, which has been undergoing testing since October 1992. In white, the Vulcain engine mockup (Photo courtesy of Aérospatiale)

The process of stage integration takes about 7 months and has three main phases:
- pre-integration of the forward skirt and thrust frame in specialised bays
- rivetting of the pre-integrated forward skirt to the tank delivered by Cryospace
- final assembly and functional tests performed in the large integration bays.

During these phases, the stage's electrical and fluid systems are activated by a command control system produced in cooperation with Matra (F), ETCA (B) and Iberespacio (E).



The H155 stage Integration Building
– On the right, stage integration bays
– In the centre, integration bays for the forward skirt
– On the left, the 45 m long transport container



H155 integration cycle

After the customer has taken delivery, the stage – protected in a container built by Genius Klinkenberg (NL) – is transported first by river and then by sea to the Guiana Space Centre.

The production process will gradually be validated in the course of the integration and inspection operations carried out on the various development units. A first milestone has already been reached with delivery to the industrial architect in November 1992 of the H155 stage dynamic mockup for system testing.

The H155 'battleship' stage

Optimisation of the test sites has led to the construction in Kourou of a development test facility for the so-called 'battleship' stage. It consists of reinforced tanks and a real aft part, both assembled on a support structure that is mounted on the launch table. This facility, built by Aérospatiale in cooperation with Air Liquide (F), Escher and HCG (NL), arrived in French Guiana in February 1992. It is currently being used to validate the propellant-filling facilities at ELA-3.

In the second half of 1993, a stage aft part and bays containing the onboard electrical systems will be added so as to complete this H155 'battleship' stage, which will then be used for the first functional hot tests.

Conclusion

Alongside the work of Aérospatiale itself, all activities concerning the propulsion system, including the Vulcain engine, are also on schedule. It can therefore be said that the situation of the stage's development early in 1993 is very satisfactory and there is no doubt at all that the industrial and programme teams will be ready to go ahead as planned with the first hot tests on the H155 at the Kourou launch site in French Guiana in January 1994.

The H155 battleship-stage stand in the launch zone during a safety demonstration. The pale yellow item is the Ariane-5 launch table, and those in white and green the battleship-stage stand. (Photo courtesy of CNES/CSG)

Deployment of Eureca from Space Shuttle "Atlantis" in progress

The Eureca and TSS Deployments – A Breakthrough for European Space Technology and Operations

An interview with ESA Astronaut Claude Nicollier

Flight STS-46, from 31 July until 8 August 1992, was one of the Space Shuttle programme's most demanding missions to date. In its payload bay, the Shuttle Orbiter 'Atlantis' carried two new types of spacecraft on their way into orbit: ESA's retrievable carrier 'Eureca', a platform containing a variety of experiments in the fields of microgravity sciences, space physics, astrophysics and solar physics; and the Italian tethered satellite TSS-1, designed to study the dynamic and electrodynamic behaviour of tethered systems in space.

ESA Astronaut Claude Nicollier was the first non-American ever to serve as Mission Specialist on a Shuttle mission, and he describes his impressions in this interview with Jochen Eichen of the European Astronauts Centre (ESA/EAC) for ESA Bulletin.

Q: *What is the main message do you think, Claude, after this successful flight?*

CN: Well, it was certainly a very interesting mission, full of surprises and unexpected events! From a European viewpoint, I think that this mission has demonstrated a significant expansion of our capabilities in manned spaceflight, from both the technical and operational points of view. Eureca and TSS-1 were new systems that had never been flown before, and with very useful potential applications in the future.

As far as operations are concerned, it was the first time that we departed from 'doing science onboard Spacelab or MIR' (apart from Jean-Loup Chrétien's EVA outside MIR in 1988). We are maturing. We are slowly starting to acquire the operational knowhow that will be needed if we are to participate fully in the assembly of the European elements of Space Station 'Freedom'.

Obviously, the experience gained is valuable not only for the onboard crew, but also for the ground team, in both the mission preparation and execution phases. The ESA Eureca ground team, incidentally, did an excellent job in recovering from the various spacecraft anomalies that we experienced during the mission.

We need to continue doing science onboard Spacelab. This is a very important part of getting ready to operate experiments aboard Space Station 'Freedom', but we also need to continue expanding our expertise by being fully involved in Shuttle system management, proximity operations, use of robotics, EVA, etc. Beyond 'Freedom', the experience acquired will help us with future European spaceplane operations, although we may have to wait for quite a while before this happens.

Q: *How long was the training in preparation for the STS-46 mission?*

CN: I was assigned to this particular flight, as Mission Specialist No. 1, in the autumn of 1989, together with Mission Specialists Jeff Hoffman and Franklin Chang, and Italian Payload Specialists Franco Malerba and Umberto Guidoni. The other crew members, the Commander, Pilot and the fourth Mission Specialist, were assigned later.

The main reason for the early assignment of three of us, plus the Payload Specialists, was that there was a lot of work to be done in the design of tethered-satellite operations and tethered-satellite science. In fact, my involvement in the tethered-satellite programme had started as early as 1985, when I worked on this programme whilst at the Johnson Space Center, in parallel with my generic space flight training. So, as you can see, several of us started being involved with the mission long before the start of the formal mission-specific training at the end of 1991.

Q: *What can you tell us about the different phases of this formal training?*

CN: Let me start at the time I was assigned to this mission, in September 1989. For the Eureca platform, I worked with the ESA, ERNO and JSC teams supporting the design of the platform's deployment and possible contingency retrieval operations. A lot of time was also spent participating in the design of the onboard displays and of RMS (Remote Manipulator System) operations. I was the only one in the Astronaut Office to work on Eureca.

For TSS, I was mainly involved in work related to tether dynamics and satellite control, together with Jeff Hoffman, while Franklin Chang and the Italian Payload Specialists worked on the science aspects. The whole payload crew (Mission and Payload Specialists) also undertook several 'science tours', in the USA and Italy, to attend briefings on TSS dynamic and electrodynamic science.

The crew of mission STS-46

Once the complete STS-46 crew had been assigned in early 1991, with the addition of Commander Loren Shriver, Pilot Andy Allen, and Mission Specialist Marsha Ivins, most of the subsequent training was done in the various simulators, rehearsing every phase of the mission, and practising operational work-arounds for a number of failure scenarios. We also performed a number of so-called 'joint integrated simulations', with the participation of the remote Payload Operations Control Centre (POCC) at ESOC in Darmstadt (D) for Eureca, and of the Science Operations Centre at JSC in Houston (USA) for the TSS. The training was very intense. There was no time for holidays, or even single leave days, for the six months preceding launch.

Q: *You were really mission-dedicated at that time?*

CN: Absolutely, I would say more than 100%. You have to understand that this mission was very ambitious; we had two major payloads, Eureca and TSS, and each of these payloads, in terms of operational complexity, would have justified a dedicated Shuttle mission of its own. What helped a little was that the crew was divided into two alternating teams, the Red and the Blue, which somewhat reduced the training load for each of us, but we still had to be cross-trained to a certain extent, to ensure scheduling flexibility.

As far as Eureca was concerned, its deployment was basically a Blue Team responsibility, with Andy Allen as Shuttle Pilot and myself as RMS operator and platform systems operator. In the event of a contingency retrieval, Loren Shriver would have piloted the Shuttle, and I would still have handled the RMS and Eureca systems. We trained that way.

Contingency EVAs were practised by Jeff Hoffmann and Franklin Chang, and I supported part of this training as RMS operator. For instance, we practised the manual folding of Eureca's solar arrays and antennas, the manual release of Eureca's retention latches, and a number of TSS contingencies requiring EVA. I also took part in all the ascent and re-entry training, as I was to be on the flight deck for these two phases of the mission.

Q: *You must be the ESA Astronaut who knows the Shuttle system best as you have been involved as a Mission Specialist. How would you describe its complexity?*

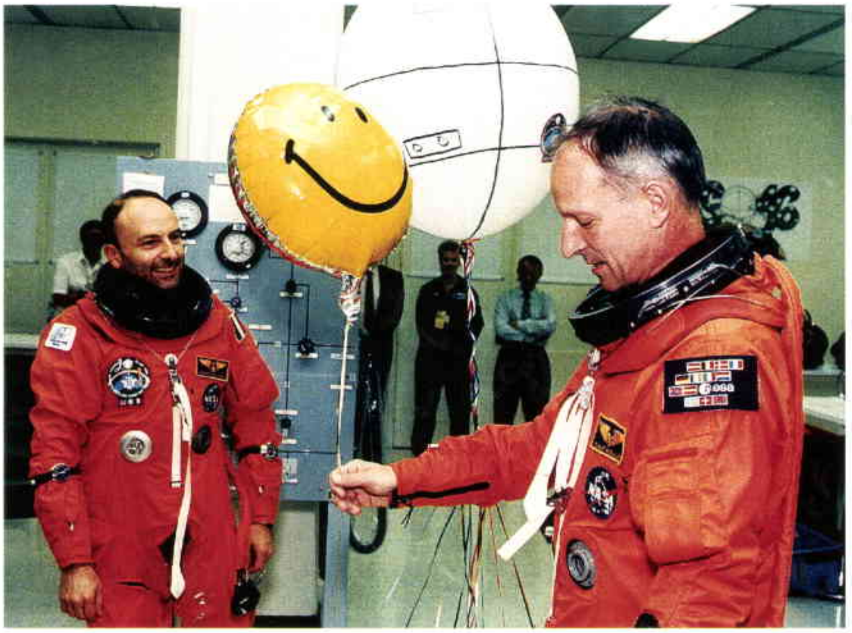
CN: The Shuttle is a very complex vehicle. It is also a very capable vehicle. I am thinking here particularly of the Shuttle's sophisticated in-orbit guidance, navigation and flight-control systems. Its electrical power, environmental-control and life-support systems are relatively straightforward, but the data-processing system is not very user friendly and its understanding requires a lot of training and practice. We lack expert systems in the Shuttle that would help the operators in diagnosing malfunctions, or guide them in system troubleshooting. This translates into a massive flight data file (procedures on paper) that we have to carry onboard, and practice its use before the mission.

Q: *On this flight, crew workload was very heavy. Obviously, the training could not cover all of the activities you had to carry out in space. Did you have any difficult times during this flight?*

CN: We had some hard times, this is true!. Fortunately, 'Atlantis' performed very well, including all systems and the RMS. The problems we had were all payload-related. This was not too surprising, as the Shuttle was on its 48th flight and it has been improved and fine-tuned over the years to reduce the incidence of failures. Its reliability is due also to the excellent work done by the NASA and contractor teams that prepare the Shuttles between flights at KSC.

Both major payloads, Eureca and TSS, were flying for the first time on STS-46, and when you do something new in space you can expect that things might not work exactly as planned.

On Eureca, the remote Payload Operations Control Centre in Darmstadt, and we on board, lost essentially all spacecraft data after the platform's data-handling system was activated. This was shortly after unberthing the platform from the payload bay. Following suggestions by the ground team, we did some troubleshooting of our own, switching Eureca antennas and selecting an alternate payload signal processor in the Shuttle, but without success. It was found later that there was an incompatibility between the telemetry frame sent by Eureca and what the Shuttle's payload communication system could cope with. Proper spacecraft data was, however, being received via a direct link with an ESA ground station, and in particular Kourou, which was operational at that time.



Astronauts Franco Malerba (left) and Claude Nicollier

This glitch translated into a delay in releasing Eureca from the Shuttle: we eventually performed this operation shortly before orbital midnight on the 27th orbit. The reason for the delay being about 24 hours was that we had to be in synchronism with the Blue/Red shift schedules. The release had to be a Blue

The launch of mission STS-46

shift activity. As the problem was severe enough to require more than a few hours of delay, a full day of delay was budgetted, with a sleep period in between for the Blue team.

We had several problems with the TSS. One of the satellite umbilicals would not release, and we finally had to use 'brute force' to effect separation. Later, after successful initial fly-away, the deployment stopped at about 10 cm tether length, and we had to reel the satellite back in and start again. The significant problems, however, were reel jams at 180 m and 256 m tether lengths. We finally had to reel the tether back in from that 256 m, which was far short of the planned 20 km deployment.

Claude Nicollier at work in orbit

Q: *Anyhow, despite all of your experiences during the deployment of both payloads, the mission was a success. Even with this relatively short distance between TSS and the Shuttle, it was the first time that this combination of spacecraft had flown in practice. Can you comment on the flying of the Shuttle itself?*

CN: Well, as we only achieved a short tether length, it meant that there was always a low tension in the tether. As both the gravity-gradient force and the centrifugal force – which together are responsible for the tension in a tether along a local vertical direction in low Earth orbit – are proportional to tether length, the short tether meant a low tension. Tether tension was also supposed to maintain the satellite's attitude in pitch and roll. There was a backup satellite attitude-control system in the form of pitch and roll cold-gas thrusters, commanded by the crew, to be used in the event of loss of tension in the tether (slack tether). We used those a lot!

As far as flying the Shuttle itself was concerned, this task was shared between Loren Shriver, the Commander, and Andy Allen, the Pilot. Andy did the flying during Eureca station-keeping post-release, and Loren flew most of the manual manoeuvres during the TSS operations. This was no easy task. The goal was to maintain the Shuttle's relative position with respect to the satellite at all times, the altitude of the Orbiter being maintained by the digital autopilot. Some tricky slack-tether management was also performed, flying the Orbiter manually following the sudden stops at 180 m and 256 m of tether deployment.

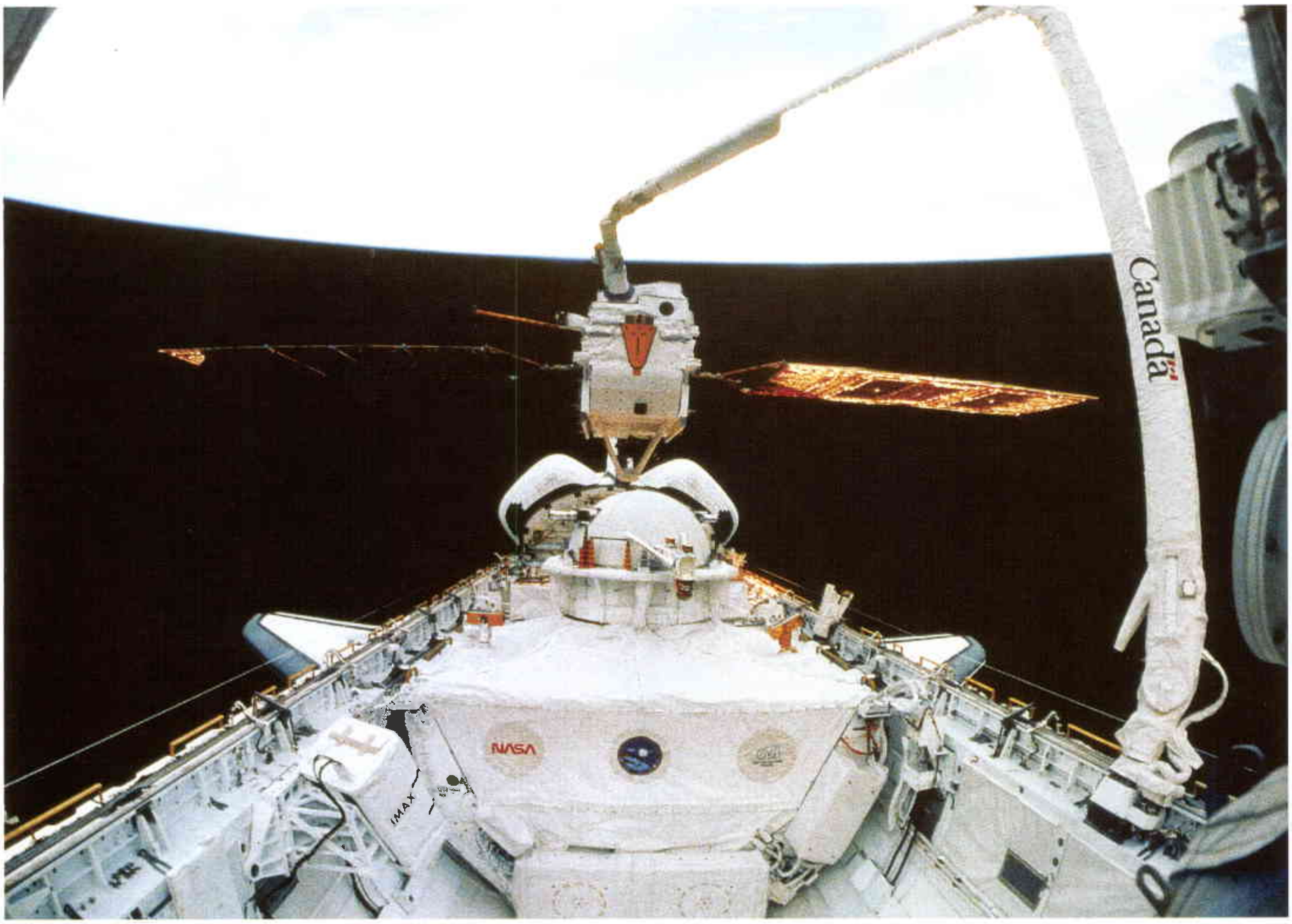
Q: *Were the commands from the Shuttle to the satellite sent through the tether or were they radio-linked for tele-operation of the satellite thrusters?*

CN: Data from the satellite was received by standard radio-frequency (RF) downlink, and commands were sent to the satellite by RF uplink, using the Orbiter's S-band payload communication system. The tether was conductive, but no intelligent signal was sent through it, as it was a significant part of the tether experiment to measure the current induced in it as a function of tether length and geometry, location of the Orbiter/TSS system in the geomagnetic field, status of electron generators in the payload bay, etc.

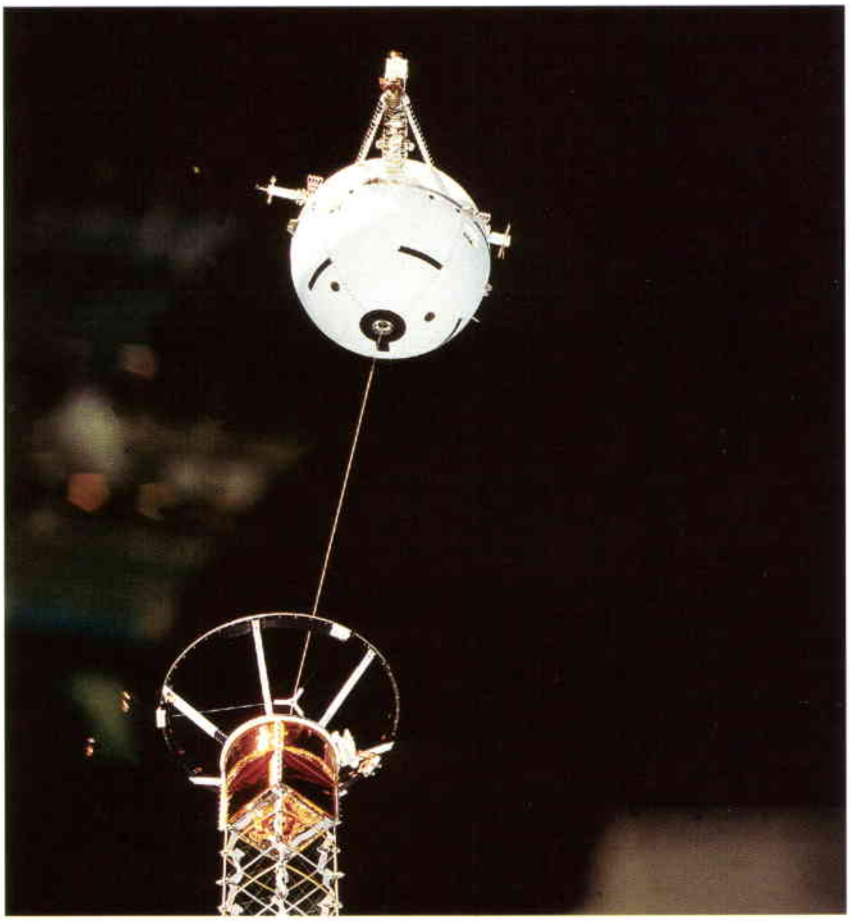
Q: *Was the training adequate for what really happened in space?*

CN: I think it was. We could not have done any more with Eureca or the TSS had we had more training. No amount of extra training would have helped us resolve the problems that affected the TSS, as nobody knew the cause of the jams, and now that we know what happened there would have been no real-time fix possible anyway.

I would say, however, that the extra training we got during the three weeks just prior to the mission itself was invaluable. During several sessions in the Shuttle Mission Simulator, we practised the teamwork necessary to recover from slack-tether situations and the associated loss of natural TSS attitude control. We put all of this training to work during the subsequent mission, and much more than we had ever imagined! I really think that without that extra training we



Eureca being deployed from the Shuttle's cargo bay



Deployment of the Italian TSS-1 satellite

would not have been able to keep the TSS-1 satellite under control during the critical phases of its deployment and retrieval.

Q: *The complexity of this operation was perhaps in some way a preparation for Space Station operations at the end of the decade. Was the experience gained on STS-46 significant for the Space Station assembly process?*

CN: Any space flight increases your level of readiness for any subsequent mission, and this one was, obviously, no exception. I have already mentioned how this flight expanded our operational envelope and allowed us to acquire new skills and expertise beyond doing science in Spacelab.

I also think that the whole STS-46 mission-preparation scenario, involving multinational teams in a highly complex operation, was very fruitful. Our mission involved three space agencies – NASA, ESA and the Italian Space Agency (ASI) – and all of the teams worked very well together, in a spirit of cooperation and understanding. This is good news for Space Station 'Freedom'!

Q: *From an astronaut's point of view, what do you have to say about the current status of Space Station 'Freedom' in the USA?*

CN: I think that we are finally reaching stability in the Space Station architecture, and people are working hard at JSC on the issues of Space Station element assembly. This is going to be an interesting exercise, exploiting the Shuttle's resources to the limit. We need to be sure, as full partners in this programme, that we Europeans are fully involved in this part of the programme.

Swiss Federal Councillor Mr Delamuraz welcomes back Claude and Susana Nicollier at Geneva Airport after the STS-46 mission (photo Alain Morvan)

Q: *So you believe that European astronauts will be involved in this operation?*

CN: New ESA astronauts were selected in 1992 specifically for this purpose, and also to work on the Space Station after assembly is complete. I hope that these astronauts will have opportunities to fly on the Shuttle before the assembly flights for the European elements, for instance on Eureca deployment and/or retrieval missions.

Q:*So Eureca is the smallest man-supported free-flyer?*

CN: It is indeed, and I hope that we will make use of this facility a few times before the 'Freedom' era to do science in space using the long-duration space-exposure capability of the platform. In addition, it will give us opportunities to familiarise ourselves, as Europeans, with such space operations as rendezvous proximity operations, grappling and berthing a (relatively) massive payload, refurbishing it for later re-use, etc.

These are areas where we need, eventually, to further our abilities. Eureca is a great tool with which to learn. I hope that, on future Eureca flights, Europeans can also get involved in the deployment and recovery operations as full members of the ground-control team in the Mission Operations Control Room.

Q: *We have seen the enthusiasm generated in your country by you as a Swiss Astronaut. How can we proceed to stimulate more enthusiasm in other parts of Europe? Would you say that manned spaceflight is still a great challenge for mankind?*

CN: I think that it is important to show the public what we do, and to explain why we do it. A lot of people in Switzerland, and also elsewhere, were only marginally interested in space activities before the mission, but when we tell them our story they find it fascinating and it generates a lot of enthusiasm. People are awakening to the great challenges of manned spaceflight. Unusual challenges and how we cope with them, both in flight and from the ground, is something that fascinates the public.

Q: *It is a basic philosophy within ESA to strive to present Europe's space activities in an open and easily understandable manner. What would you see as the political message from a flight like STS-46?*

CN: I am not sure I can give a political message, not being a politician myself. My overall advice, however, would be the following: let us keep up the momentum gained last year (1992) in the area of manned spaceflight. If we cut back too much, dissolve teams, and dilute programmes over time, then the resulting loss of momentum will be difficult to recover from in the future.

European Astronaut Candidates in Training in the CIS

M. Cheli-Merchez, C. Fuglesang & P. Duque
European Astronaut Candidates, European Astronauts Centre (EAC), Cologne, Germany

For four weeks in October and November 1992, we – three European Astronaut Candidates from the European Astronauts Centre (EAC) in Cologne – were fortunate enough to have the opportunity to live and be trained in Star City. It proved to be a fascinating experience, both for us and the EAC Training Engineer, Antonio Torres, who accompanied us.

Introduction

About 35 km northeast of Moscow lies the town of Zvyozdny Garadok, or 'Star City'. It is here, at the Yuri A. Gagarin Centre for Astronaut Training, that all Russian astronauts have received training since 1960. With some 4000 inhabitants, Star City is completely devoted to the task of training and preparing astronauts for manned space missions.

The training programme at Star City offered us a wide selection of the training courses that the Russian astronauts follow. Our curriculum included theory lessons, Mir and Soyuz simulations, space-suit training, parabolic flights, special medical training, as well as psychological and physical training. Above all, we were very impressed by both the professionalism of all of the people involved and their kindness and sincerity. Our stay also afforded us invaluable experience in living and working with our Russian colleagues.

Training and courses

The training was made up of a balanced mixture of theoretical lessons and practical sessions in the simulators, complemented by various physical exercises. Generally speaking, we found the summaries we received very informative; the instructors were condensing very long courses into 2 h overviews, and this seemed to work exceptionally well. The practical sessions in the simulators were modelled on the actual work performed by Russian astronauts in the first stages of their training.

We were impressed by how adaptable and responsive to our suggestions and comments the instructors and planners were.

The accompanying table summarises the subjects covered and the numbers of hours devoted to each theme.

Topic	Lecture Hours	Practice Hours
Psychological Training	4	3
Soyuz Flight Plan	4	—
Soyuz Structure and Configuration	5	—
Physical Training	—	16
Vestibular Training	—	8
Aviation and Space Medicine	4	—
Spacesuit 'Sokol'	4	6
Orbital Complex Mir	10	16
Centrifuge	—	4
Soyuz Operations	—	14
Soyuz Motion Control System	6	—
Fundamentals of Space Navigation	8	4
Earth Remote Sensing Methods	9	—
Low Pressure Chamber	—	5
Soyuz-Mir Approach and Docking	2	2
Parabolic Flights	2	7
Visit to Mission Control Centre	—	4
Totals	58	89

These sessions were preceded by an initial two-hour 'Welcoming Session', at which we were introduced to the training staff at the Centre and to our instructors.

We had a detailed three-hour medical examination during the morning of the second day. A visit to the neutral-buoyancy facility, a large tank 23 m in diameter and up to 10 m deep, was also put into the programme at our request.

Finally, there was a Press Conference on the last afternoon of our visit, during which a video containing clips taken during the different stages in our training was shown.

This was followed by a tour of the Centre for the visiting journalists.

Psychological training

We were surprised to find that the first and last lessons of our programme were devoted to this subject, which shows that the training concept in the CIS is quite different from that in the West. The latter places greater emphasis on the technical capabilities of the trainees, taking it for granted that they will be able to apply them efficiently whilst employing their own personal ways of coping with problems, there even being a sense of embarassment about seeking psychological-type help. For the Russians, the first and most important issue is ensuring that those going into space are given all available means to remain healthy, and therefore efficient; technical abilities are secondary to this focal point.

The psychological training that we received focussed on the basic techniques available for regaining one's stability and self-confidence after, or even during, periods of severe stress. All available sources of information are exploited, the material that we received having been compiled from classical psychology together with the most ancient Yoga wisdom. All in all, we were very positively impressed.

Soyuz flight plan

As an introduction to many of the other lectures, we received a simple explanation of the orbital path that Soyuz follows from launch to its docking with Mir, and from

A Typical Day in Star City

At 8.15 am we left our hotel, called the 'Profylaktorium', and walked about a kilometre to the training centre canteen, at which we had all of our meals – breakfast, lunch and dinner – on weekdays. The breakfast choices were porridge, 'cipikanka' (a kind of cheese cake), some kind of hamburger, and tea.

At 9.00 am, the first lesson of the day started, a two-hour lecture on space navigation. The lecturers and instructors spoke only Russian, with a few exceptions. We therefore had to rely on our interpreters for much of the time. This worked surprisingly well and only occasionally – typically when we had very technical questions – did we run into communication problems. The lecturers were also very good at keeping to their allotted times, and always gave us 5–10 minute breaks every hour.

After the theory lesson, there was an hour of psychological training, including relaxation exercises, after which followed the vestibular training. During the latter, we sat in a rotating chair, or similar support, making movements with the head and trying to avoid being sick for as long as possible! If you do not call a halt in time, it can take several hours to recover completely!

Lunch, taken between 13.00 and 14.00, was our main meal of the day, and the food was similar each day: a plate of vegetables and perhaps a piece of fish, soup, some meat with potatoes or something similar, and finally tea. The only other drink availble was water, or water flavoured with dried fruits.

After lunch, there was a two-hour simulation session in the Soyuz model, including wearing the appropriate space suits. The Soyuz capsule is not very large and our knees protested during these sessions!

The day's programme ended with two hours of physical training. This included warming up, some sport like tennis, basketball or football, a 20 minute workout on muscle-building machines, and then finally, always, a swim followed by a sauna.

Dinner in the canteen, at around 18.00 h, was generally a piece of meat or sometimes fish – there was usually a choice of three or four dishes, but after two weeks you knew them all – followed by a cup of tea (generally very good).

The evenings we spent back at the hotel, reading, playing cards and trying to get in contact with home base (EAC in Cologne). We had been provided with two lap-top computers with built-in modems, and after some days we were given a telephone line from one of our apartments to Moscow. We could dial-in to IKI in Moscow, from where there is a direct line via the ESA network to EAC. Sometimes this link worked, and sometimes not; when it did work it was usually plagued by lots of communication errors.

undocking to landing. This served as a first glimpse of orbital mechanics for the uninitiated, covering the injection orbit, manoeuvring, phasing orbit, approach technique, relative motion in close circular orbits, and re-entry paths.

Soyuz structure and configuration

The Soyuz spaceship that shuttles between the Earth's surface and the Mir Space Station was described in some detail in this series of lectures, which included functional descriptions of all of the subsystems that were to be used in subsequent, more practical lessons. The different compartments of the spacecraft were described, together with the locations of the various system elements (manoeuvre boosters, life support, communications, power, etc.) and their usage during various stages of the mission. This also served as a good general introduction to spacecraft construction.

Physical training

This aspect is given, consistent with the Russian training concept, a high priority in the overall scheme. We received a comprehensive programme of training that included normal physical activities, but it was not difficult to see that it was very much geared to the specific needs of spaceflight. Physical endurance, team spirit, muscle building in particular critical areas, and swimming abilities were coached, always with an instructor. The physical stresses involved in Extra-Vehicular Activity (EVA) are considerable and the Russian trainers therefore have two different types of ultimate goal to be achieved: for those expected to use the 'Arlan' EVA suit, and those who are not.

Vestibular training

Most of you will have heard about 'space sickness': it is common for astronauts to experience this unpleasant symptom during the first hours, or even days, of their work in orbit. This sickness is similar in some respects to what one can experience when sailing or flying, or on fairground rides like roller-coasters.

The Russian approach to the problem is that motion sickness must be regularly provoked in astronauts to prepare them for space flight and allow them to learn to control their reactions. We had a taste (or rather a distaste!) of all of their machines devised to induce fast and controlled sickness. We found it difficult to overcome our natural fear of this kind of discomfort, in order to approach the training in a positive frame of mind. Our training period was too short for us to note any substantial improvement, although one of us did seem to perform better towards the end.

However, not all doctors, particularly those in Western Europe, are yet convinced about the usefulness of these exercises.

Aviation and space medicine

The doctor in charge of us there, Sergei Polikanov, pointed out that 'as the technological development is not high enough to assure the same working conditions in space as on Earth, special requirements must be fulfilled by space flyers'!

Figure 1. Pedro Duque beside a model of the Mir Complex

We were given an overview of the medical issues of spaceflight, and the concepts used at Star City to improve the ability of astronauts to withstand the hardships. We were also given a very interesting lecture on the biomedical experiments conducted aboard Mir.

The 'Sokol' spacesuit

This is the safety suit worn inside Soyuz by the astronauts when there is any risk of a decompression. It is a one-piece suit, with a chest opening covered with rubber, and a pair of rubber gloves. We learnt how to put it on without haste and ensuring safety, how to operate the control valve, and how to attach it inside Soyuz. In addition, we had a couple of practical sessions in which we performed nominal and contingency operations inside the capsule. We worked for a while with the suit inflated and could feel how it hinders your actions.

The Mir orbital complex

The largest part of the training plan was obviously devoted to the configuration and operation of the Mir Space Station. We received dedicated lectures on the systems of all modules and got acquainted with the simulators and mock-ups. Several subsequent sessions were dedicated to the simulation of routine operations aboard Mir, including commanding via the various computers, the handling of several life-support systems, some use of the Earth-observation equipment, and the performing of Station manoeuvres.

Figure 2. Christer Fuglesang emerging from the docking port of the Kvant Simulator

Centrifuge training

We participated in two centrifuge training sessions, the first of which was the basic programme as followed by the Russian astronauts. The routine consists on a 'warm-up' phase of 4 g, lasting 1 min, and a training run at 8 g, lasting 30 sec. During the initial 4 g phase, the subject is expected to practise the breathing technique to be used during the higher loading phase. According to the doctors in charge, this training has a measurable effect on the subject's tolerance of high g-loadings which lasts for about one year.

The second centrifuge session provided a simulation of the loads experienced during launch and re-entry, exposing the test subject to a gradual increase in load and then abrupt drops, simulating the firing of the three rocket stages. The maximum load is about 3.7 g. During the real re-entry, the maximum load is seldom more than 4 g, but because the astronauts have been in zero-gravity for some considerable time they perceive the load as being much higher. The simulation protocol therefore imposes a maximum loading of close to 7 g and, for about 2 min the load is above or around 4 g.

Soyuz operations

Under this topic we can include the simulator sessions of several kinds that were conducted inside the Soyuz simulator, including normal in-flight operations like manoeuvre preparation and monitoring, and simulation of automatic docking. The automatic and manual re-entry modes were also simulated. These sessions formed the basis of the normal training procedure, being complemented later with the necessary contingency rehearsals.

Soyuz motion-control system

A number of lectures were devoted to the Soyuz Attitude and Orbit Control System (AOCS) and its operating modes. Aspects studied included the physical layout of the thruster system providing the control forces, the axes of the spacecraft and their alignment with external reference directions by means of infrared and solar sensors, the strap-down inertial platform and its operation.

Fundamentals of space navigation

This series of lectures was intended to provide a brief introduction to the mechanics of spaceflight, and some of the geometric principles on which the attitude-determination sensors are based. These are basically star sensors, and the mathematics of their use for attitude determination was touched upon. All Russian space vehicles carry a manually operated attitude determination system (a type of sextant), and we also received a couple of training sessions in the planetarium on the use of such instruments.

Earth remote-sensing methods

The Mir station contains a series of cameras that are routinely used for observation of the Earth. Some lectures were devoted to several very general principles of Earth observation, and also to the study of some specific examples of images taken from Mir and their interpretation. The role of the astronaut as an intelligent observer was given central billing during these lectures, the concept being that only through intense training and long practice can one produce scientific Earth observation results successfully.

Low-pressure chamber

As part of the medical examinations, we were subjected to low pressures equivalent to heights of 5000 and 10 000 m (with air and pure oxygen, respectively). We spent 30 min and 15 min, respectively, at these pressures. The second time we performed a long pre-breathing sequence with oxygen at ambient pressure to remove the nitrogen dissolved in the blood.

Soyuz–Mir approach and docking

We had a session on the simulator for manual docking on Mir, preceded by a lecture on the operation of the controls and the recommended strategies for approach, fly-around and docking. Several dockings under different conditions were simulated, with the instructor evaluating the correctness of our manoeuvres and especially the final position and velocity data.

Parabolic flights

An Ilyushin-76 MDK aircraft was put at our disposal for a day, and we made two flights, with 10 parabolas being flown on each flight. The experience is quite different from what one feels in a smaller aircraft like the Caravelle, because the enormous volume of the cargo bay (about 3.5 m in diameter and 14 m long) produces a very special sensation when in a parabola. We performed a strict exercise programme to get acquainted with microgravity conditions. Starting with the gradual achievement of a good feeling for moving just with the help of the hands on a rail, we continued with little 'flights' from one place to the other, the handling of bulky or heavy objects when strapped down, and the putting on and taking off of the space suit in zero gravity.

Safety, we should add, is paramount in Russia, and the parabolic flights were a good example in this respect. Every 'beginner' (as we were considered) has an experienced parachutist to take care of him/her, making sure for example that everybody reaches the floor safely after each parabola. Everyone in the aircraft must wear a parachute during take-off and landing, and the flight crew often keep theirs on during the operations. The beginners also wear both head protection and gloves, to avoid injury from contact with hard surfaces or hot lamps. These and similar measures help the beginner to feel absolutely safe, which significantly steepens the learning curve.

Visit to the Mission Control Centre

We asked to visit the buildings from which the ground operations are conducted in order to have a glimpse of the other end of the link. The 'TsUP', as it is known, is located in Kaliningrad, not far from Star City. It contains a couple of main control rooms with enormous map, slide and TV displays, with observation seats above for visitors, and standard three-screen consoles resembling those used at ESA's own centre in Darmstadt (ESOC). These very large main control rooms are used for the Mir Station and (nominally) also for the Buran spaceplane. Four smaller control rooms are used for Soyuz, Progress, the unmanned Earth-orbiting and the deep-space missions.

Life in general

Star City has the air of a military installation, with many of fences and gates, and one needs a pass to enter. We, in fact, rarely had

Figure 3. Marianne Cheli-Merchez preparing for an 8g centrifuge ride

Figure 4. Left to right: Pedro Duque, Marianne Cheli-Merchez, Christer Fuglesang and Antonio Torres in the Earth Observation classroom at Star City

to show our passes, as we were soon 'well known' visitors. In all other respects the town looks much like any other, but the standard of living is presumably higher in Star City than in most other Russian towns.

There are two special houses containing larger than usual apartments for astronauts and their families. They typically occupy a three-room flat covering about 80 m^2, which is spacious by normal Russian standards. Foreign astronauts training in Star City for more than just a few weeks are also given flats there. Star City has most things one would expect to find in any small town: shops (although not always easy to find), cafe/restaurants, cinema, library, hotels, schools, etc.

We were living in a special hotel, the 'Profilaktorium', which was built to house the US team during the Apollo–Soyuz programme. Astronauts returning from space now spend their initial rehabilitation period in the calm environment of this hotel, in three two-room apartments. We were each given one of these apartments, which well equipped with TV, radio, fridge, electric kettle and telephone. It was not generally possible to call outside Star City, but one could in principle call in from abroad, with a little patience. We were lucky enough to have our own satellite-telephone, which we mounted in one of the apartments, and this usually worked well and allowed us to keep in touch with our families.

Before going to Russia, we were given 8 h of Russian-language training. This was just enough to teach us the Russian alphabet and to say things like 'Hello', 'OK', and 'I don't speak Russian'. Since only a few people there speak English (or German or French), it was not always easy to communicate, even though we always carried pocket dictionaries with us.

At the Training Centre, however, there was a very warm and friendly atmosphere and even when we were without the interpreters we managed somehow. We soon felt quite at home and that we had many friends, some of whom spoke excellent English and showed us around Moscow during the weekends.

During the weekends, we visited museums in and around Moscow, did some shopping, and varied our eating habits somewhat (McDonalds and Pizza Hut!). Frequently, we were invited to make visits and people from the Training Centre arranged the trips for us. One of the most impressive things that we saw was a military Air and Space Museum, housing an enormous collection of aircraft, dating from the beginning of the century up to the most modern Russian planes like the MIG-29. Many of the planes were unique, like the pre-Buran prototype spaceplane. During our stay we also went to see a ballet and an opera at the Bolshoi Theater. On one occasion, we were all invited to a grand lunch hosted by the Spanish Ambassador.

There were astronauts from Germany and France in Star City at the same time as we were there. Klaus Flade, who flew on Mir in March 1992, and his backup Reinhold Ewald were there for a three-week refresher course, which also included some new things for them such as EVA-training in the Neutral Buoyancy Facility. The next French astronaut to fly, Jean-Pierre Haigneré, and his backup Claudie Andre-Deshaye, arrived two weeks after us. Jean-Pierre, who was Michel Tognini's backup this summer, is scheduled to make a three-week flight to Mir this summer. He now faces an intensive eight-month training period. Finally, two other Frenchmen, Philippe Perrin and Michel Viso arrived during our last week there, for a six-week training programme similar to our own. We very much enjoyed the company of these colleagues, and in particular we were able to benefit from the experience of those who had been to Star City before.

There was also public Russian interest in our training. A few days after we arrived there was a radio news item about us and we were later featured in a TV news programme. We were even recognised the day after when out and about in Moscow. There were many Russian journalists and a TV-team at our final Press Conference, as well as the familiar journalists and TV reporters from the ESA Member States.

On the last evening of our stay, we invited all of our instructors, trainers and course organisers to a farewell dinner at one of the cafe-restaurants in the town. We were honoured in that both the Head of the Training Centre, General Pyotr Klimuk, and his Deputy, General Yuri Glazkov, came along.

Conclusion

The first ESA Astronaut training period at the Yuri Gagarin Astronaut Training Centre in Star City was certainly highly successful from our point of view. During four full weeks, we learnt much about Soyuz, Mir, space navigation and other related subjects, while the many simulation exercises gave us a good grounding in how things will work in reality. The physical, psychological and vestibular training that we received and the special medical exercises that we underwent showed what a complex endeavour training for manned spaceflight really is!

During our stay in Star City, we gained first-hand experience of how the Russian astronaut training is conducted and got a good taste of it for ourselves. Their professional abilities, both in terms of knowledge and pedagogics, are outstanding. They also have many impressive facilities, such as the centrifuges, neutral-buoyancy facility, the aircraft for parabolic flights, etc. Their experience in training astronauts, acquired over a time span of more than 30 years, is substantial. The planned continued cooperation with the Yuri Gagarin Training Centre should prove very fruitful both for ESA and the CIS.

The contract that has been concluded between ESA/EAC and Star City covers not only the four-week training period in 1992 reported upon here, but also consultancy support for future space training and medical operations, and a three-month training period for ESA Astronauts at Star City in 1993. As the ESA Council meeting at Ministerial Level in Granada last November decided to embark on closer cooperation with the CIS, which includes two Mir missions in 1994 and 1995, the training activities planned for 1993 may link directly into the Mir mission training.

Acknowledgement

We would like to thank all of the EAC staff for the considerable support that we received from them in preparing for, and during our visit to Star City, and in particular our EAC 'man on the ground' Antonio Torres. Our deepest thanks go to all of our instructors and friends in Star City. We are looking forward to going back to learn more, by which time we will endeavour to speak Russian!

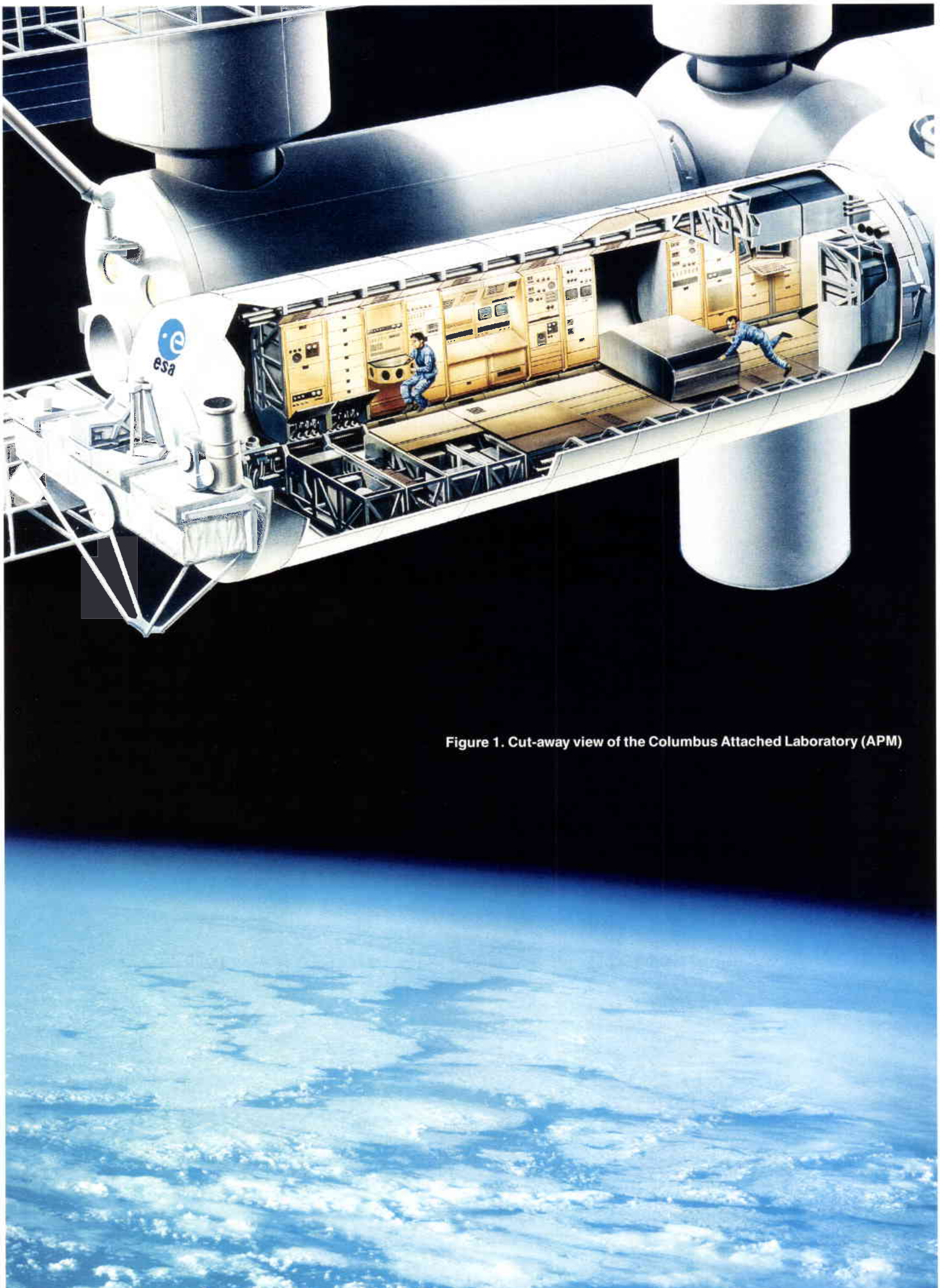


Figure 1. Cut-away view of the Columbus Attached Laboratory (APM)

A Standardisation Policy to Support Columbus Payloads

F. Ongaro
ESA Directorate for Space Station & Microgravity, ESTEC, Noordwijk, The Netherlands

C. Bunkenborg
Weltraum-Institut Berlin, Germany

The payloads for the Columbus Attached Laboratory will be the first to be developed as in-orbit-serviceable units. This will entail a new design philosophy, one prominent aspect of which is standardisation. The 'Columbus Payload Standardisation Study' has taken the first step in addressing this issue.

Introduction

The Columbus Attached Laboratory (APM)* is itself designed for a lifetime of 30 years, whilst its payload facilities are expected to have in-orbit stay times of up to 5 years. Such lifetimes can realistically be achieved only by supporting the in-orbit exchange of scientific facilities and failed parts. From an engineering and operational standpoint, such support, which we will broadly call 'servicing', requires that all items and interfaces that need to be serviced by the crew be standardised to some extent. The introduction of a standardisation policy is also an obvious requirement when looked at from a crew-training, tools, and storage availability point of view. However, applying it to something as unique and specialised as scientific instruments is far from straightforward.

A first step in identifying those areas in which the benefits of standardisation justify its introduction has been taken in the 'Columbus Payload Standardisation Study' performed by a consortium of the main European microgravity payload developers. The two basic ground rules for the study were:

1. **Standardisation is to be investigated only as a support to in-orbit servicing.** This means that the areas addressed by the study were those which could meaningfully be called serviceable, both in terms of crew times and skills required, and in terms of 'uniqueness'. For example, Printed Circuit Boards (PCBs) can be found in almost all facilities, and therefore standardising them may facilitate in-orbit maintenance. On the other hand, standardising the components on the PCBs themselves is not meaningful from a servicing point of view, because the time needed to localise, correct and verify a fault at component level on a PCB makes this activity unrealistc in orbit.

2. **Standardisation shall never be an obstacle to the scientific objectives of the facility.** For example, various facilities use lasers as diagnostic tools, but each uses a very specific type, which therefore cannot be standardised without compromising the specific needs of the experiments.

In-orbit servicing

One major obstacle for this study is already evident from the example cited under ground rule 1 above. In choosing the level at which standardisation is to be introduced – electronic box, PCB or component – a criterion for weighing crew time spent on the activity against the mass to be exchanged is necessary. The lower the level of repair, the higher the number of interfaces to be broken, and therefore the longer the time necessary to perform – and previously train for – that particular operation. Conversely, the higher the level, the higher the mass to be brought to orbit. Since both resources, crew time and upload, are limited to the 12.8% ESA allocation of Space Station Utilisation resources, giving roughly 900 kg of pressurised upload, at least 300 kg of which are to be reserved for scientific samples, and 600 h of crew time, a 'rule of thumb' adopted by the study team was: 1 h of crew time is equivalent to 1 kg of upload. Other factors also come into play in this choice, such as the skills and tools needed to perform the operation in question.

* Originally known as the Attached Pressurised Module, or APM

Standardisation of replaceable parts is a key element in supporting the in-orbit servicing of various experiment facilities. However, the experiment facilities themselves need to be designed according to specific guidelines to allow safe and reliable servicing activities to be performed by the crew. This is a very important aspect and one which is being investigated in a parallel activity to develop the so-called 'Payload Servicing Breadboard', which will constitute the first realistic Columbus Serviceable Payload.

Needless to say the two activities are closely linked and mutually beneficial.

What is a standard?

There are almost as many good arguments against standardisation as there are in favour, and one must be very careful in using the term. First of all then, it was necessary to define what was meant by a 'standard' in the context of this particular study. According to the dictionary, a standard is 'Something set up as a rule for measuring or as a model to be followed'. As this seemed too general for the task in hand, the following 'types' of standard were used by the study team:

Type A: Standard Item

These items are defined by a commonly agreed set of documentation that provides sufficient information to manufacture the item. The standard defines such properties as:
- interfaces
- performance
- material properties (incl. material treatment)
- testing
- manufacturing processes.

Items manufactured according to the standard will guarantee performance within a defined tolerance range. There is usually more than one manufacturer for these items.

Examples
- DIN or LN screws
- military connectors
- AN fittings.

Type B: Interface or Functional Standards for Compatibility and Exchangeability

For compatibility and exchangeability of items, this standard defines all relevant properties to allow the manufacture of items that are mutually compatible or exchangeable. The standard includes the definition to the extent necessary of:
- interfaces
- performance.

Items compatible within these standards may differ in all design areas not established by the standard, but guarantee compatibility with respect to the properties specified. This type of standard allows different manufacturers to produce compatible items.

Examples
- data bus
- serial interfaces
- sensor characteristics.

Type C: Common Items

These items are defined to the extent necessary for the intended use by the payload developer. Typical areas to be specified are:
- interfaces
- performance
- environmental conditions
- test methods
- lifetime
- quality control.

This quality-control information is not sufficient to manufacture the item. Usually only a single manufacturer is available. Full interchangeability and minimum performance of these items is guaranteed. Their choice is usually driven by development costs.

Examples
- valves
- displays
- electronic boards
- pressure regulators
- pumps.

Type D: Common Design

A common design is introduced by a set of design guidelines or requirements that cover a certain area of a group of items, the functions of which are similar but not identical. Interchangeability is not intended, but a kind of 'standard' on a higher level has to be established.

Examples
- method to indicate payload status, type of information provided
- arrangement of operating elements on a front panel
- type and location of fasteners to be opened during servicing of a data box; arrangement of PCBs inside the box
- support structures for payloads
- software tasks (e.g. data acquisition, safety supervision).

An illustrative analogy that helps in understanding the types of standards is provided by drawing the parallel with a car:

the light bulbs and fuses, which come from different companies but have very well defined interfaces and performances, will be Type A. The wheels, which can come from different companies, look and perform differently (weight) but must still must fit the same hubs and carry the same tyres, will be Type B. The engine, which may have different performances but must fit all relevant interfaces and is generally from a unique company, is Type C. The pedal lay-out in the car conforms to a Type-D standard.

What shall we standardise?
Standards will not be introduced in payloads for the first time with the Columbus APM. The motivation for applying them may be different, but certain types of standards have also been applied on earlier Spacelab payloads. A review of these, why they were used and the experience gained was the first task of the Columbus study, in order to apply this experience in deriving the guidelines for selecting the standards for the Columbus era. The boundary conditions of the Columbus scenario and the existing Columbus Payload Studies were also reviewed in this same assessment phase.

One prime area of standardisation is that of system interfaces. Wherever the payload meets the system, it encounters a standard, be it the mechanical mounting to a rack, the protocol for exchanging telemetry and telecommands, or the maximum allowable temperature of its front panel. The same will be true for Columbus also, and the only area of interest to the study team in this respect was in examining which of the standards developed or adopted by the

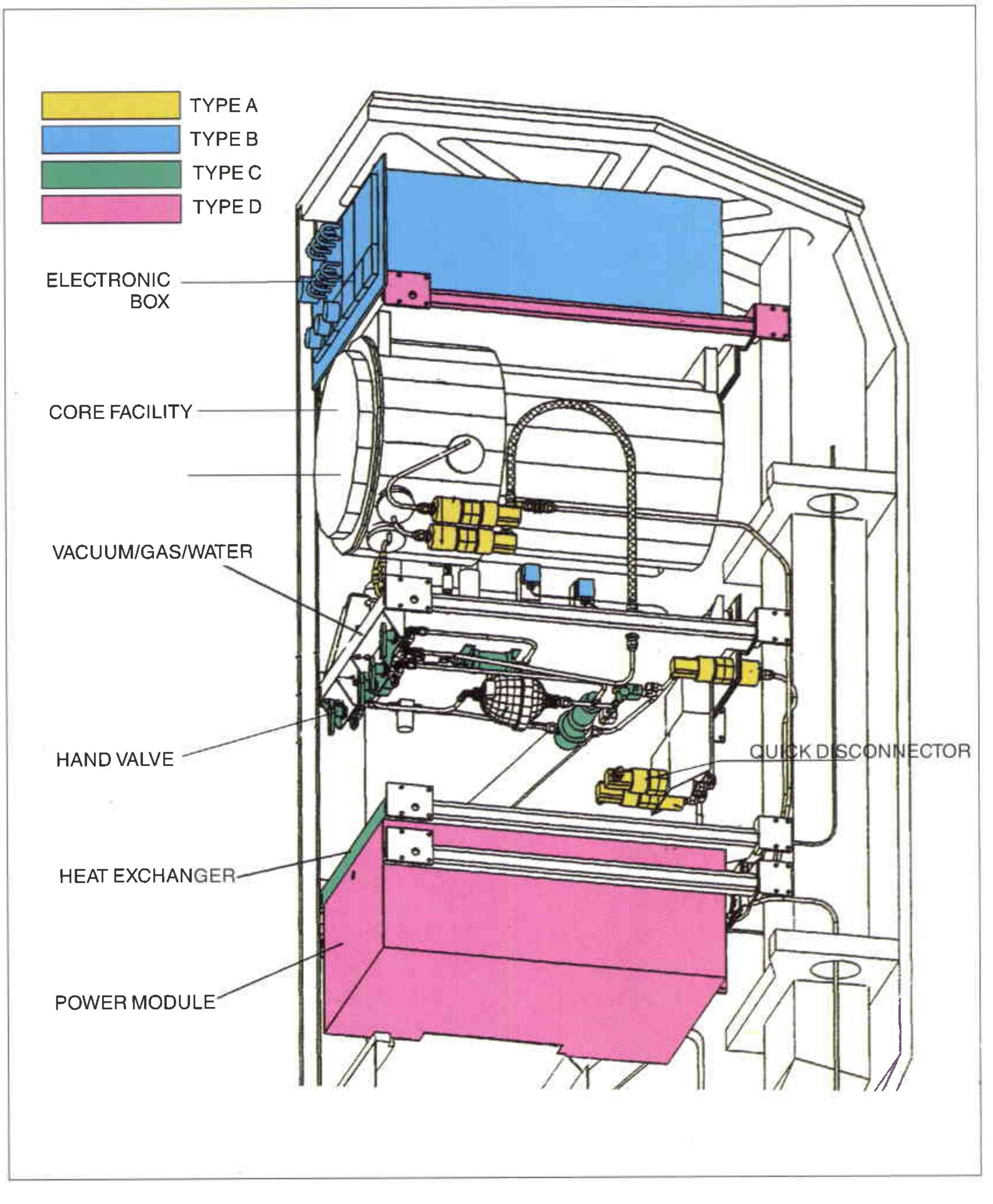


Figure 2. The Columbus Attached Laboratory's water system. Colour coding highlights the various 'types' of standard.

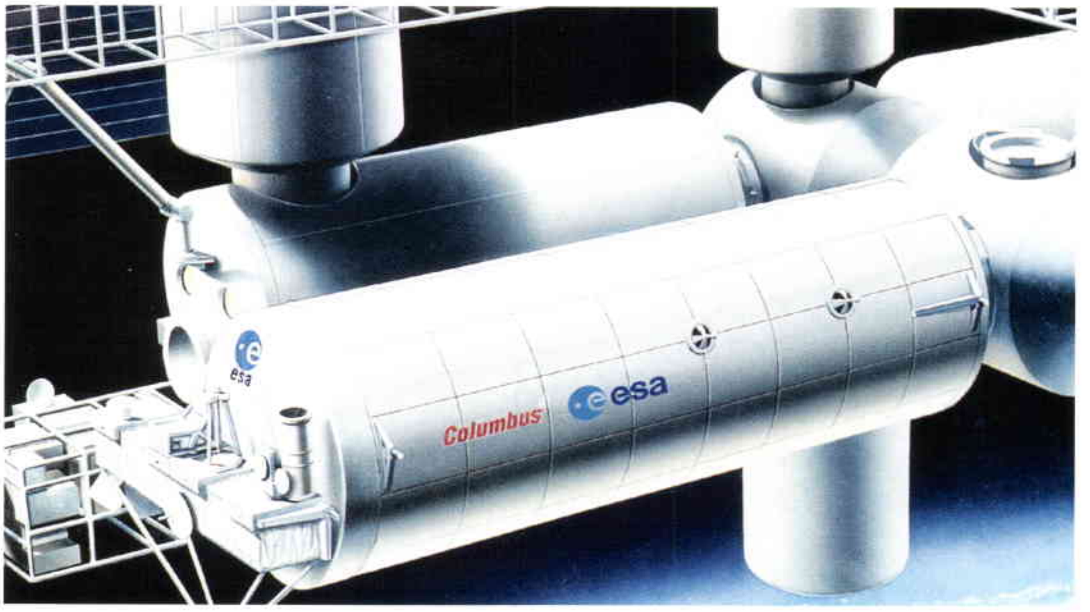


Figure 3. The Columbus Attached Laboratory mated to the Space Station 'Freedom'

system should also be adopted by the payload (e.g. the human/computer interface standards, the 120/28 V DC power converters for valves, etc.).

Another area where partial standardisation had been introduced in the past was that of 'in-house' practice. Each of the companies had its own approach to the various aspects of subsystems design (e.g. four companies had four different data-handling approaches) and its own pool of reliable suppliers, which were carried over from one project to the next. This kind of standardisation could be termed 'vertical', because it applies only to the products of one company. In contrast to the vertical standardisation which was economically motivated, the decision to adopt a horizontal standardisation approach is driven by servicing considerations only.

Some of the main lessons identified in this first task, and the resulting recommendations for the Columbus APM, could be summarised as follows:

1. Standardisation, even at component and subassembly level, is an integral part of the overall design and operations concept. Hence the final definition of standards calls for close technical cooperation with the payload design and development activities.

2. In those areas where rapid developments in technology are expected, interfaces and functions should be standardised, rather than individual items. Choice or development of a standard is a very delicate process in these cases and technical problems associated with standard items used in the past have lead to increases in costs and decreases in mission success.

3. The appropriate level of standards for payloads differs significantly in most cases from system recommended standards (Columbus Preferred Parts List and In-orbit Replaceable Unit definition).

4. Standardisation of existing Spacelab payload-element items was essentially driven by development aspects (reduction of risk) and by the given Spacelab payload-system interfaces. The Columbus payloads, with servicing as an integral part of onboard operations, represent a very different scenario.

5. Onboard servicing of Columbus payload elements will introduce a new design aspect with a considerable impact on the architecture, volume and mass of payload elements. A well-balanced payload-element scenario must be based on a reasonable sharing of payload-element resources (up/down load, onboard storage, crew time) between servicing needs and nominal experimental operations.

6. Servicing will be strongly supported by corresponding standardisation of the items to be serviced. The servicing and standardisation requirements have to be incorporated as early as possible into the design of Columbus payloads.

7. Columbus payload elements should provide sufficient built-in support to identify and localise failures/malfunctions, thereby reducing the servicing efforts demanded of the crew. A corresponding

philosophy has to be established that essentially allows a trade-off between loss of experimental capabilities in the event of payload failures and the resources required for payload servicing.

Out of this exercise came a list of over 100 'candidate standards' identified in the review of Spacelab payload experience, and a 'Standardisation Handbook' containing Guidelines derived from the lessons learned, with which to screen current and future candidates. This screening process is a sort of 'logical sieve', meant to verify the rationale according to which a candidate standard is proposed. The actual selection of a candidate also depends, of course, on the design of the facilities that will adopt it and other considerations. This very important iterative step could not be completed during the study time frame, and is still in process. A preliminary screening was, however, performed, both to prepare the first step of the above-mentioned iteration and to verify the validity of the Guidelines outlined below.

Out of this process, 43 items were retained.

GUIDELINE 1

An item that is used at least twice in Columbus facilities and requires on-board spares, on-board tools or check-out equipment, should be standardised.

Q1: Is an item used more than once?
Q2: Are on-board spares required?
Q3: Are tools or check-out equipment required for the item?

GUIDELINE 2

All items that have a direct crew interface and require frequent crew activity should be standardised.

GUIDELINE 3

Items that require frequent crew activity or extensive crew time for servicing should be standardised at least with respect to the crew interface for servicing.

Q4: Does the item have a crew interface?
Q5: Does the item require frequent crew interaction?
Q6: Is the item subject to regular servicing, maintenance and repair?

GUIDELINE 4

Items that are handled by the crew and which are critical to operational safety (hazardous operation of Category I) should be standardised.

Q7: Is the operation of the item hazardous?

GUIDELINE 5

Items that represent a high development risk/cost and for which several users exist should be standardised.

Q8: Can development cost and risk be reduced?

GUIDELINE 6

Items, interfaces and performance requirements that relate to a standard item should be considered for standardisation.

Q9: Does the item have an interface to another standard?

A second notable difficulty at this stage is highlighted by the first question in the Guidelines, namely: 'Is the item used more than once?'. This refers to what we referred to above as 'horizontal' standardisation: the servicing motivation applies primarily to standards that are common across various facilities. Does it make sense, therefore, to impose or develop a standard for items used by one facility only? Typically, this is already solved at the facility level, as in the case of the sample containers, which are standard for a given furnace or centrifuge, but certainly not interchangeable between the two, and where the only area of commonality may be found in the man/machine interface (e.g. coding, identification, etc). It is easy to see that for many of the standards that one would wish to introduce, whether the first Columbus mission will be composed of two, three or more racks of scientific facilities will make a big difference in the selection process.

Table 1. Existing standard

Item	Single Item (S) or Family (F)	Rational
Bolts	F	Servicing, tool standard
Connectors inside payload	F	Servicing
Fitting interface	F	Crew interface, servicing, tool interface
Fan	F	Servicing
PT 100	S	Secondary standard
Quick disconnect	F	Servicing
Vacuum valve	S	Servicing, logistics
Solenoid valve	F	Logistics
Vacuum pump	F	Development costs
Filter	F	Servicing
Expt. processor bus	S	Secondary standard
Indicators	F	Crew interface
Indication std.	S	Crew interface
MMI/HCI	S	Crew interface
Pressure sensor	F	Logistics
Keypad	S	Crew interface
Display	S	Crew interface
Switches		Crew interface
Electronic circuit breakers	F	Servicing
DC/DC converter	S	Servicing development costs

Table 2. Proposed standard

Item	Single Item (S) or Family (F)	Rational
Electronic box	S	Servicing, crew interface
Sliding rail	S	Servicing
DC-motor	F	Servicing
Video camera head	S	Servicing
Gas bottle	S	Servicing, development costs, secondary standard, logistics
Overpressure relief valve	S	Development costs
Multimeter	S	Crew interface, servicing tool
Battery package	S	Secondary standard
Pressure regulator	S	Servicing
Interface to DMS	S	Servicing, logistics, development costs
NuBus/Multibus II CPU PCB	S	
NuBus/Multibus II PROM PCB	S	
NuBus/Multibus II RAM PCB	S	Servicing, logistics
NuBus/Multibus II Digital I/O PCB	S	
NuBus/Multibus II RS 422 I/O	S	
NuBus/Multibus II Analogue I/O PCB	S	Servicing, development costs
NuBus/Multibus II Video switch	S	Logistics, development costs
PT 100 I/O	S	Logistics, development costs
Power supply Multibus II	S	Logistics, development costs
Manual power switch	F	Crew interface, development costs
Fasteners (harness)	F	Servicing and crew interface
De-gassing device	S	Servicing and crew interface
Knobs, handles	F	Crew interface

Where are we now?

Having identified a certain number of 'logically sound' standardisation candidates, the study team proceeded to search existing aerospace, laboratory and Columbus system standards (adopted or under development in this last case), to determine whether they could meet the requirements. This proved to be the case for 20 of them (Table 1). For the remainder (Table 2), a subset was prioritised and preliminary specifications generated for this subset (for which ROM costs and schedule estimates were also provided).

All of the above information has been collated in the Final Report, which will be made available to the Columbus Payload Studies teams. Their feedback on the acceptability of the proposed standards, their possible modification or the proposal of new ones, will be a key step – both technically and politically – to the implementation of an effective standardisation policy for Columbus facilities.

Work is still in progress in one specific area, namely that of the 'Electronics Box'. As mentioned above, standardisation of a PCB format and perhaps of a few 'common' PCBs (e.g. power supply, system LAN interface) can go a long way to enhancing payload operations and reducing upload. This means selecting a PCB format and a 'backplane bus' (i.e. the data bus that connects the PCBs in a computer and which therefore dictates the PCB standard) standard.

Currently the Columbus system is developing and qualifying a backplane bus dedicated to the subsystem computers, and a series of related PCBs. This option has the advantage of being available to the payload developers fully qualified at recurring costs. However, it is developed according to very stringent safety requirements, which make it a 'unique' development for which no commercial equivalent for software or hardware exists. This situation limits the potential for future growth of this standard, and binds the payload developer to a single supplier for both hardware and software, both for the flight model and for the development, qualification and training models. Past experience has shown this to be a very expensive proposition.

Another option would be to verify the possibility of flight qualification – to a lower reliability standard than the one needed by the system – of existing commercial PCBs without modification of their performance. If this possibility is confirmed, only the specifications for the (existing and commercially available) bus, guidelines for the flight qualification and serviceable drawer design and perhaps the qualification of the above-mentioned 'common PCBs' would need to be developed. The payload developer would have to conform to these directives in the design of the facility, but would be free to choose the hardware and software architecture that best suits the scientific requirements, and also to profit from the continuous evolution of commercial products.

Clearly this would also bring economic savings due to the possibility of developing all ground-based equipment from purely commercial products, thereby freeing resources for the development of more scientific instruments. Just as clearly, all of these benefits are viable only if the flight qualification does not change the PCB performance, and on this the jury is still out at this time, although a decision is expected in the first half of 1993.

Conclusions

As the study progressed, it was confirmed that the planned Columbus in-orbit operations make standardisation highly desirable. Areas affected include:

Crewtime: today's Spacelab payloads reflect a low level of standardisation. Applied to Columbus operations this would entail different training scenarios for each servicing operation, different spares and tools in orbit, and the consumption of more crew time than necessary. In the extreme, no servicing, only replacement of drawers, would be feasible. Regardless of the particular facility being worked on, for a number of items, the same operations would have to be performed. As a consequence, the time required for the preparation, checkout and verification of the task can be significantly reduced by standardisation, because these will become routine operations for the crew.

Logistics: although replacement parts will need to be transported to orbit in any case, standardisation minimises the number of tools that need to be transported and stowed in orbit. Furthermore, if lower-level servicing is made possible, as in the case of a standard Electronics Box and PCBs allowing for exchange at the PCB rather than at drawer level, this may allow for up to forty-fold savings in uploading needs, and radically improve scheduling flexibility.

Utilisation: crew time and uploading will be two of the most critical payload resources on the Space Station. Whatever can be saved in terms of repair times and materials can be used for scientific work and samples. Furthermore, the availability of in-orbit spares for critical items can reduce unplanned downtime for scientific facilities. This can have quite some impact in the case of life-limited samples.

Cost: this was not considered a driver in this study. However, especially for safety critical items, requiring lengthy and costly certification processes (e.g. pressurised vessels), and for high-development-cost items (e.g. turbo-molecular vacuum pump), standardisation is a very attractive possibility.

Standardisation has its disadvantages, of course. The responsibility for the performance of a mandatory standard shifts from the payload developer to the customer. This aspect was not examined in detail here, as it depends on various factors, including: type of standard, overall procurement framework, future Agency policy concerning Columbus payload acceptance, etc. These are important areas to be addressed as soon as the first technical iteration is completed, in the first half of 1993.

Acknowledgement

The authors wish to extend their thanks to the Columbus Payload Standardisation Study Team members: Mr Briccarello of Alenia (I), Mr Lenski and Ms Neuhaus of Dornier (D), Mr Vidal of Matra Marconi Space (UK), and Mr Zier of ERNO (D), who contributed to many of the concepts reported here.

Europe's First Space Law and Policy Summer Course

P.H. Tuinder
European Centre for Space Law (ECSL), ESA, Paris

The European Centre for Space Law (ECSL), founded in 1989 with ESA support and operating under the Agency's auspices, provides an informal framework within which to conduct activities that will promote research on space law and policy matters in Europe. ESA supports the Centre because space-law studies in Europe in the past have proved to be somewhat uncoordinated and often ad hoc in character. This state of affairs has not only weakened the research activities themselves, which have tended to be carried out on a purely national basis, but has also meant that potential researchers have failed to secure optimum support for conducting their activities.

Introduction

One of the steps that ECSL has taken to promote interest in and knowledge of the law related to space activities has been the establishment of a 'Space Law and Policy Summer Course'. The first Summer Course – unique in Europe – was held on 7–16 September 1992 at the University of Messina, in Sicily (I). It was sponsored by ESA, the European Community (ERASMUS Programme), ECSL, the British National Space Centre (BNSC), and the University of Messina.

Eight Universities from five ESA Member States participated and forty students (five per University) attended the ten-day Course, for which there was no participation fee. The students were selected by their sponsoring Universities. Apart from having followed classes in international law, they had to have a good knowledge of French or English, and a working knowledge of the other language. Thirteen lecturers attended to teach space law (lectures being given in English or French) and five tutors assisted the students in making their final presentations.

The 1993 Course is already in preparation and the interest of Universities in participating is growing quickly. It has been decided to limit the number of students admitted to future Courses to around forty, to ensure active participation and optimal interaction between students and lecturers and between the students themselves.

Course organisation

Preparations for this first gathering in Messina started in 1989 when the ECSL Board expressed the wish to create such a Space Law and Policy Summer Course in order to stimulate students to undertake research on space law and policy in Europe. After having secured support from ESA and the European Communities' ERASMUS Programme, the programme for the Course was finalised and the sessions organised at the premises of the University of Messina in Sicily. Additional financial support was provided by BNSC.

The first Summer Course was designed around one general topic providing an overview of the basic principles of space law, namely an 'Introduction to Space Law', and several special themes of space law on which eight (student) working groups made their presentations on the last day. These working-group presentations each lasted half an hour and were followed by a discussions with the students on their presentations.

Each working group, consisting of five participants from different Universities and guided by a tutor, addressed a particular space-law issue chosen from the special themes in the Course curriculum. Each group also attended a one-hour training session on how to use the ESALEX electronic database for their research. The background documentation for the Course and the presentations, prepared by ECSL, was divided into eight syllabuses covering the eight themes for the presentations.

Course content

The Course was created with a two-level structure in mind. First an introduction to space law was given in order to brief the students on the main aspects of and latest developments. The second part of the Course was centred around a number of special themes which allowed the professors and the students to analyse specific topics in depth, whilst at the same time illustrating the main lines of development in space law covered in the first part. The themes chosen were based on current developments and issues in space law and will therefore change from year to year.

In the 1992 Course, the Introduction, consisting of 20 h of lectures, focussed on the United Nations framework, Treaties and Resolutions (8 h); the United Nations Resolutions of 1958, 1961 and 1963; the Outer Space Treaty and other space treaties; the United Nations Principles concerning Direct Television Broadcasting and Remote Sensing; the role of the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) Legal and Technical Subcommittee, the United Nations Outer Space Division, and the subjects currently on the UNCOPUOS agenda.

Figure 1. The class of 1992

1992 Summer Course Lecturers

Prof. K.H. Bockstiegel, University of Cologne, Germany

Drs. F.G. von der Dunk, University of Leiden, The Netherlands

Prof. J.M. Faraminan, University of Granada, Spain

Dr. M.F. Ferrazzani, ESA Legal Affairs, Paris

Dr. K.M. Madders, ECSL, Paris

Prof. P. Malanczuk, University of Amsterdam, The Netherlands

Prof. P.M. Martin, University of Toulouse I, France

Drs. T.L. Masson-Zwaan, University of Leiden, The Netherlands

Prof. F. Pocar, University of Milan, Italy

Dr. G.C.M. Reijnen, University of Utrecht, The Netherlands

Dr. W. Thiebaut, ESA Legal Affairs, Paris

Mr P.H. Tuinder, ECSL, Paris

Prof. C. Zanghi, University of Messina, Italy.

After this Introduction, the Conventions of the various international space organisations – ITU, Intelsat, Eutelsat, Inmarsat, Arabsat, Eumetsat and ESA – were analysed (4 h). Next, the non-European national space organisations and laws (NASDA, NASA, US Land Remote Sensing Act, US Commercial Launch Act) were briefly discussed (4 h), whereafter the European national space agencies and laws were analysed (4 h). These were the UK Space Act and the Swedish Space Act and the structure of the national space agencies ASI (I), CNES (F), DARA (D), BNSC (UK), NIVR (NL), ASA (A), and SSC (S).

The second part of the Course concentrated on specific themes of space law and policy (16 h in total). Theme 1 addressed the 'Changing Structure of Europe in Space'. Here the European Community's involvement in space (policy) was discussed and several documents concerning Europe's future in space, such as the Gibson Report, titled 'Crossroads in Space', were analysed. Developments within ESA, and especially the possibilities for increased international cooperation, also received attention.

Theme 2 focussed on environmental space issues, including the problems of orbital debris and nuclear power sources.

Theme 3 concentrated on the commercial uses of outer space, including such topics as dispute settlement, the GATT negotiations, intellectual property rights in outer space, launch competition and the insurance of space activities.

Theme 4 focussed on legal aspects relating to the International Space Station and the Intergovernmental Agreement.

As the students were expected to participate actively in the Course, a number of syllabuses were given to cover the themes and ideas for preparing their own presentations for the final day of the Course.

Evaluation of the first Course

The Messina Summer Course – the first

Figure 2. Presentation in progress on the commercial uses of outer space, by one of the eight Working Groups

Participating Universities in 1993

University of Aberdeen, United Kingdom
University of Amsterdam, The Netherlands
University of Cologne, Germany
University of Granada, Spain
University of Leiden, The Netherlands
University of Louvain, Belgium
University of Messina, Italy
University of Paris, France
University of Padua, Italy
University of Rome, Italy
University of Sienna, Italy
University of Toulouse, France
University of Utrecht, The Netherlands

course of its kind to be held in Europe – was a resounding success, due in large part to the very active support provided by the University of Messina, ERASMUS, BNSC, ESA and of course the professors and students of the participating universities.

That the Course was well received by the students is illustrated by the fact that they have organised an Association of ECSL Summer Course Participants, which has already held its first reunion last December, at ESA Headquarters, at which they will be briefed on the latest space-law developments.

Future courses

At the time of writing, the process of organising the 1993 Space Law and Policy Summer Course, to be hosted by the University of Toulouse I, in southwest France, is in full swing. Letters of intent to participate at this Course have already been received from thirteen Universities in seven ESA Member States.

It is hoped that support from the European Community's ERASMUS Programme will again be forthcoming and we also hope to acquire more sponsorship in 1993 from the National Space Agencies (following BNSC's example in 1992), with a view to putting the Course on a sound financial footing for the coming years. ECSL is in the process of drafting a schedule for future courses at a variety of European venues, with the goal of stimulating interest in space law and policy matters in all of the major European Countries.

The first Course in Messina has clearly shown that interest in space law and policy is growing in Europe and, moreover, that space activities are increasingly becoming part of European society, influencing the industrial, political and cultural spheres. With the further integration of Europe, the need for increased awareness of the legal and political framework in which space activities take place is becoming ever more apparent, stimulating interest in its study and analysis.

In Brief

ESA Astronaut to Fly Second Mission

ESA astronaut, Claude Nicollier, has been selected by NASA to be a member of the crew of the Shuttle mission (STS-61) that will service the Hubble Space Telescope (see related article).

As a mission specialist, Nicollier will operate the Shuttle's Remote Manipulator System during the complex exercise. His other responsibilities will include serving as flight engineer for the ascent and descent phases, rendezvous support and Shuttle systems management in orbit.

The mission will be Nicollier's second flight aboard the Shuttle. He also participated in the STS-46 mission in July 1992, which successfully put the first European Retrievable Carrier (Eureca) into orbit (see the interview elsewhere in this issue). Nicollier, an ESA staff member, is currently in training at Johnson Space Center in Houston.

Claude Nicollier

Hubble Space Telescope to be Serviced

A Space Shuttle mission (STS-61) to service the Hubble Space Telescope (HST) will be flown toward the end of 1993. The HST, which was launched in 1990, is a cooperative effort between ESA and NASA.

When the Shuttle has captured the HST, two main tasks will be undertaken. One task will be to perform the maintenance of the spacecraft that is required to keep the HST facility operational for its projected life of 15 years. Several of the HST subsystems, such as failed gyroscope units and flight computer memory boards, will be exchanged. The two solar arrays will be replaced by a new, modified pair of ESA-supplied solar arrays.

The other purpose of the mission is to recover HST's scientific capabilities. The Wide Field Planetary Camera will be replaced by an instrument of the same design but with optics that have been modified to compensate for the spherical aberration of the HST primary mirror.

The Faint Object Camera (FOC), an ESA contribution to the mission, and the other instruments on-board will benefit from the installation of corrective optics, the Corrective Optics Space Telescope Axial Replacement (COSTAR). The COSTAR will be placed in the instrument bay that the High Speed Photometer is presently occupying. It will deploy specially-designed pairs of corrective mirrors at the other instruments' openings. These mirrors will redirect and correct the light from the telescope before it enters the instruments.

For the COSTAR programme, ESA is providing a Faint Object Camera Structure and Thermal Model (FOC/STM). The FOC/STM is a highly representative and optically fully functional copy of the Faint Object Camera. It will be used to validate the COSTAR-FOC corrective optics prior to flight by installing it together with the flight COSTAR instrument into a mechanical and optical mock-up of the aberrated HST. With the FOC/STM simulating the flight FOC in the mock-up, a complete end-to-end test of the deployed COSTAR optics will be made, and the planned in-orbit optical alignment procedures can be tested and practised.

ESA and Romania Sign Agreement

ESA has signed a cooperation agreement with the Government of Romania, covering cooperation on the exploration and use of outer space for peaceful purposes. The agreement specifies activities that both parties will be involved in, such as the regular exchange of information, mutual access to databases and laboratories, the awarding of fellowships, the organisation of joint symposia and visits, and studies on joint projects in fields of mutual interest.

This reflects ESA's political will to cooperate with central or eastern European countries, as was reaffirmed in a resolution on international cooperation adopted by the ESA Council at its Meeting at Ministerial Level in Granada on 9 and 10 November 1992. This is the second agreement that ESA has concluded with a central or eastern European country; the first one was signed with the Republic of Hungary in April 1991.

J.-M. Luton (left), Director General of ESA, and A. Vatasescu (right), Romanian Ambassador to France, sign a cooperation agreement at ESA Headquarters in Paris on 11 December 1992.

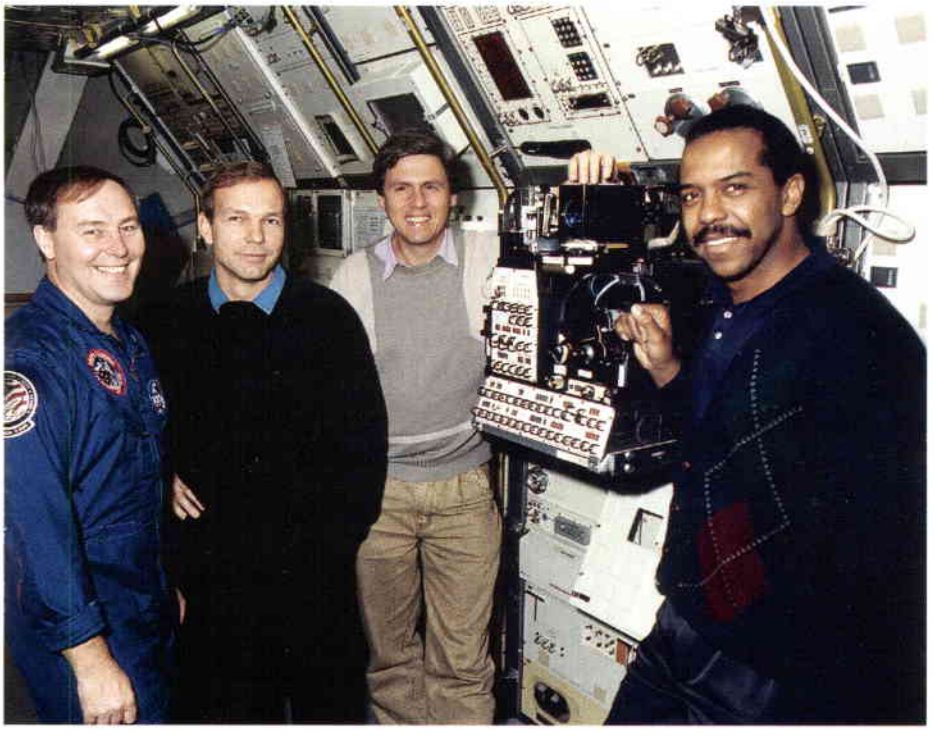
Second German Spacelab to be Launched

The second German Spacelab mission (D-2) is scheduled to be launched aboard Space Shuttle 'Columbia' on 25 February 1993. For nine days, the Spacelab, a laboratory which was developed by ESA and is carried in the Shuttle's cargo bay, will be used to conduct research in the fields of material sciences (fluid physics and material processes), life sciences (biology, human physiology and radiation biology), astronomy, Earth observation and robotics.

Two payload specialists from the German Aerospace Research Establishment (DLR) will be part of the seven-member crew; the other five astronauts will be from NASA.

During the mission, the astronauts will execute approximately 90 experiments, 32 of which European scientists have developed under ESA's auspices. Five of the ESA experiments, which relate to fluid physics, will fly in the Advanced Fluid Physics Module (AFPM), and 19 will be placed in the Anthrorack for research into human physiology in microgravity. Six other experiments in the field of material synthesis and two experiments for the Columbus Attached Laboratory, the ESA contribution to the Space Station Freedom, will also be included on D-2.

D-2 crew members training on the Athrorack and the AFPM. From left to right: Jerry Ross, Hans Schlegel, Ulrich Walter and Bernard Harris.



ERS-1 programme and products displayed at the first ERS-1 symposium in Cannes (F)

First Symposium on ERS-1 Results

During its first 12 months in operation, ESA's first Earth-observation satellite, ERS-1, has provided more than 160 000 high-resolution images of land, coastal, ocean and ice areas, and has made significant contributions to environmental research.

To review this data, ESA organised the first symposium on ERS-1 results, called Space at the Service of Our Environment, in Cannes (F) from 4 to 6 November 1992. More than 450 principal investigators, co-investigators and representatives of the pilot projects that have been using ERS-1 data, attended the event.

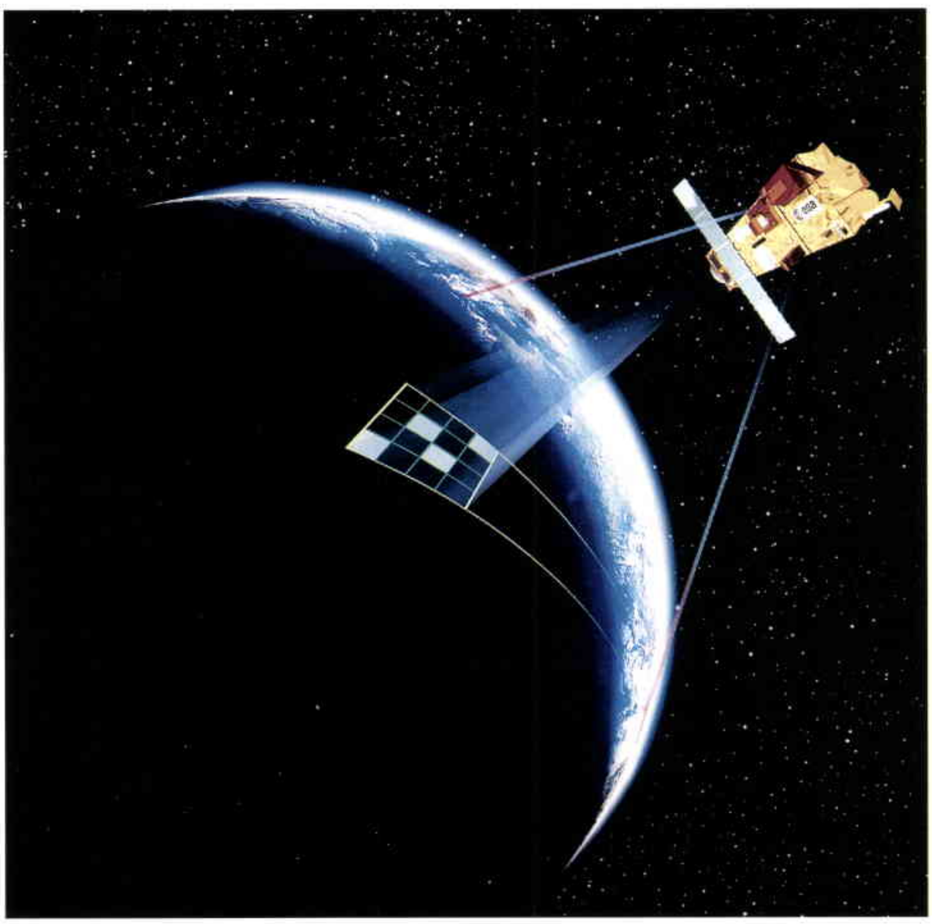
Remote Sensing in the 21st Century: Envisat-1

Remote sensing will be one of ESA's major focuses leading into the 21st century. Detailed scientific data will continue to be gathered in order to better understand the Earth and its systems, and to monitor the changes in the environment over the years and decades.

ESA's first polar platform, Envisat-1, will be launched in mid-1998. It will succeed ESA's European Remote Sensing Satellites, ERS-1 which is currently in operation, and ERS-2, which will be launched in late 1994. Like ERS-1 and ERS-2, Envisat will move in a polar orbit and will be able to scan the entire globe.

The Advanced Synthetic Aperture Radar (ASAR) will be an important feature of Envisat. Based on the SAR on board ERS-1, this second-generation SAR will make either large-scale, broad-swath images of a 400 km x 400 km area, or high-resolution, detailed images of a 100 km x 100 km area. Like ERS-1's SAR, the ASAR will be able to observe the surface of the Earth irrespective of weather conditions, cloud coverage or amount of sunlight available.

The other key instrument on board Envisat will be the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS). Using its very high spectral resolution, MIPAS will be able to measure the density and abundance of photochemically-interrelated trace gases in the atmosphere, including ozone and methane. This instrument will help scientists to understand the little-known, atmospheric gas environment.



Artist's impression of Envisat, the first ESA polar platform, with its two major instruments, ASAR (emitting wide beam) and MIPAS (emitting two thin beams). ASAR's two different methods of data acquisition are shown: capturing swath images (green box) or detailed images (grey shaded square).

'This is the Space Shuttle Atlantis Calling'

During the Space Shuttle 'Atlantis' STS-45 mission in March/April 1992, astronaut Dirk Frimout made what was probably the first direct voice contact between a manned spacecraft and ESA's research and technology centre, ESTEC, in the Netherlands.

As part of the Shuttle Amateur Radio Experiment (SAREX), Frimout, who is also an amateur radio operator, used a hand-held transceiver to communicate with radio amateurs on the ground.

The SAREX programme gives educational establishments the opportunity to talk to astronauts in space. Selected schools around the world, with a suitable amateur radio station, were able to establish communication with the Shuttle at scheduled times. Students at each school talked to the astronauts, and asked questions about space and space flight. Members of the ESTEC Radio Club, listened in to these conversations. They were also able to speak to their colleague Frimout, an ESA staff member and Belgian astronaut, and to other crew members.

Within approximately twenty minutes of its launch, the Shuttle passed over ESTEC at a range of less than 300 km. Due to the Shuttle's orbit, this favourable alignment was repeated twice a day, early in the morning and early in the afternoon. It enabled the members of the ESTEC Radio Club to use their station (with the call sign PI9ESA) to speak to the astronauts. On one occasion, for the short period that the Shuttle was overhead, a member was able to hear the transmissions using only a small hand-held portable transceiver (or 'walkie-talkie'). To be able to communicate for longer periods, the club had installed a high-gain steerable aerial that is controlled by a microcomputer and follows the shuttle once it appears on the horizon. The tracking information used was based on the predicted position of the shuttle calculated by the Traksat software programme.

Almost every time the Shuttle appeared on the horizon, Frimout could be heard saying, 'This is the Space Shuttle Atlantis calling ...'. Less than eight minutes but 3500 km later the Shuttle was gone again, disappearing over the opposite horizon.

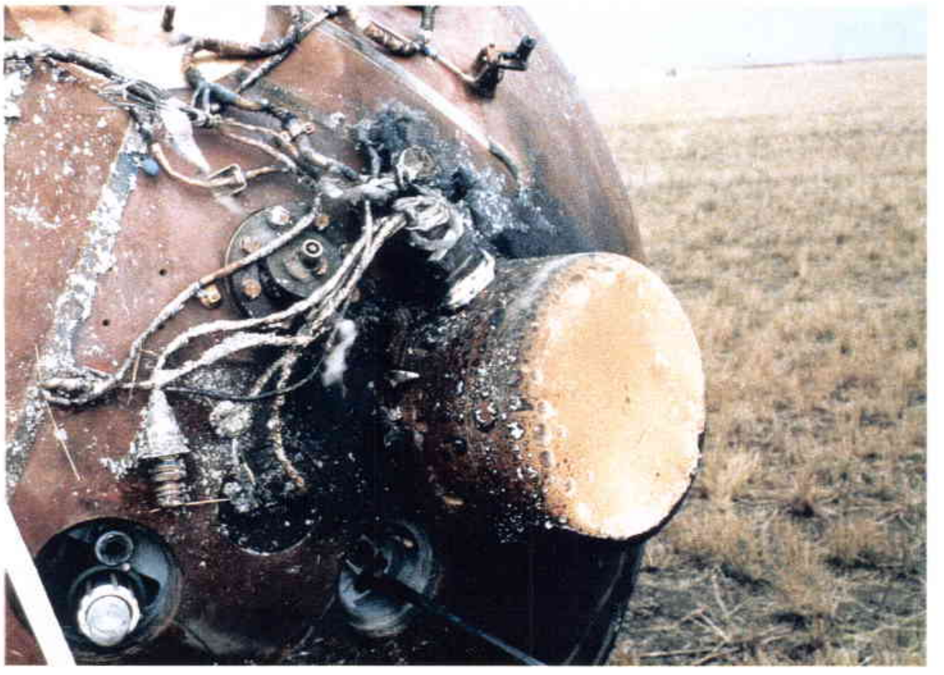
Astronaut Charles Bolden communicating with amateur radio operators on the ground, using a hand-held transceiver

Members of the ESTEC Radio Club (left) speaking to Dirk Frimout onboard the Shuttle

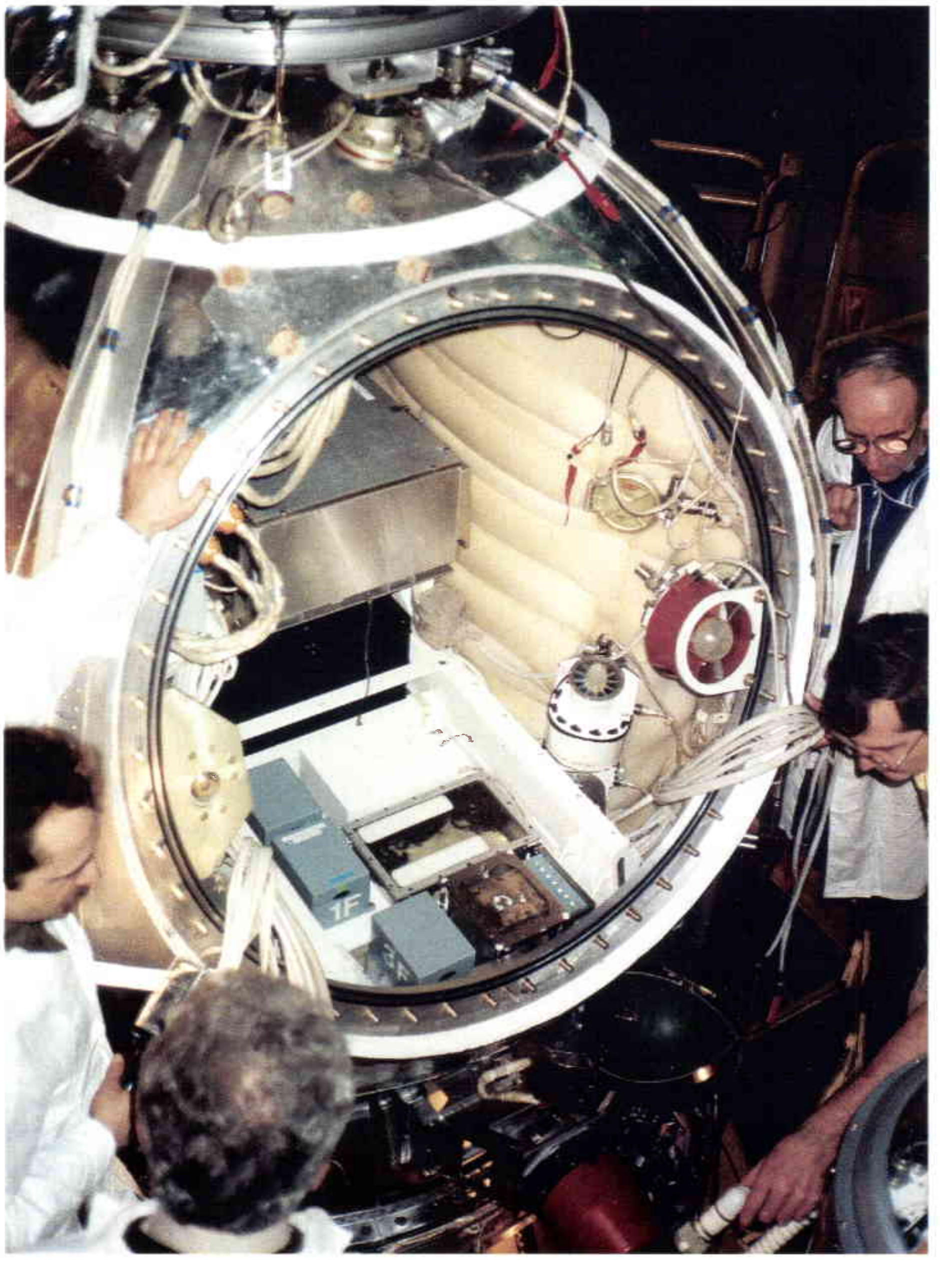
QSL card exchanged with amateur radio operators to confirm communication with Frimout aboard the Space Shuttle

Two ESA/Russian Missions Completed

For the past five years, ESA has been collaborating with Russia on research projects in space biology. To date, the partnership has resulted in the flight of three retrievable Biological Photon (or Bion) missions (in 1987, 1989 and 1992) and one test flight on a retrievable Photon satellite (in 1992). Each of the two missions in 1992 carried an ESA-developed, multi-user experiment facility: the Biopan on the first one and the Biobox on the second one.



Satellite carrying Biopan, after landing in a field in Kazakhstan



Biopan: Direct Exposure to the Space Environment

ESA's Biopan is a pan-shaped device that houses experiments and is mounted on the outside of the carrier satellite. When the satellite is in orbit, the Biopan's lid can be opened upon command and the experiments exposed directly to the space environment. Before re-entry, the lid is closed and, after landing, the experiments are retrieved and analysed.

The first Biopan model, the so-called Test Flight Unit No. 1, was launched aboard the Photon-8 satellite from Plesetsk, the Russian launch site, on 8 October 1992. It carried a payload of four experiments prepared by ESA's research and technology centre ESTEC (NL), Delft Technical University (NL), and the Research Centre for Spacecraft Radiation Safety in Moscow. After a successful mission, the satellite landed in Kazakhstan on 24 October.

The first operational flight of the Biopan is scheduled for late 1993 or 1994. The device will carry a full complement of radiation biology and exobiological experiments.

Although it was primarily designed as a multipurpose facility for space biology research, the Biopan can potentially be used for many more applications, such as in the areas of materials, components and radiation research.

Biobox (silver box) mounted in the satellite before the mission

Biobox: Studying the Effect of Microgravity on Bones

ESA's Biobox facility is a fully automatic and programmable, self-contained incubator, designed to explore the effects of weightlessness on living organisms. It weighs 40 kg and houses a centrifuge capable of reproducing in orbit the same forces of gravity as on Earth.

On 29 December, the joint ESA/Russia Bion-10 mission was launched from Plesetsk, with a payload of eight experiments. Due to thermal control problems, the satellite had to return to Earth two days earlier than planned but, in general, the payload does not appear to have been adversely affected.

Three of the eight experiments were housed in the Biobox. They investigated the effect of microgravity conditions on bone tissue and cells — the weakening of the bones in the absence of gravity is a serious problem encountered by astronauts. The first analyses carried out on some of the samples immediately after their retrieval from space indicate a reduced mineralisation in microgravity, confirming the results from earlier flights.

Three joint ESA/Russian experiments studied the effects of microgravity on the development and ageing of fruit flies, and on the cell structure development of unicellular algae. The algae experiment, which had to be performed during the final days of the flight for scientific reasons, had to be terminated earlier than planned because of the early return of the spacecraft, and will produce only partial results.

The remaining two experiments, parts of which were directly exposed to the space environment, investigated the effects of cosmic radiation on plants and seeds, and performed dosimetric studies of the radiation in the Bion-10 orbit.

Bion-10 landed in Kazakhastan on 10 January 1993. ESA and the Institute for Bio-Medical Problems (IBMP) in Moscow shared the responsibility for the project. Pre-launch and post-launch work on most of the experiments, and all engineering work on the Biobox, was done at Moslab, the ESA facility built on the IBMP's premises in Moscow.

News from the Hubble Space Telescope

ESA/NASA's Hubble Space Telescope (HST) is again proving to be a powerful and sophisticated tool for deep-space exploration. The HST servicing mission (see related article) will further improve the telescope's capabilities.

Searching for dark matter

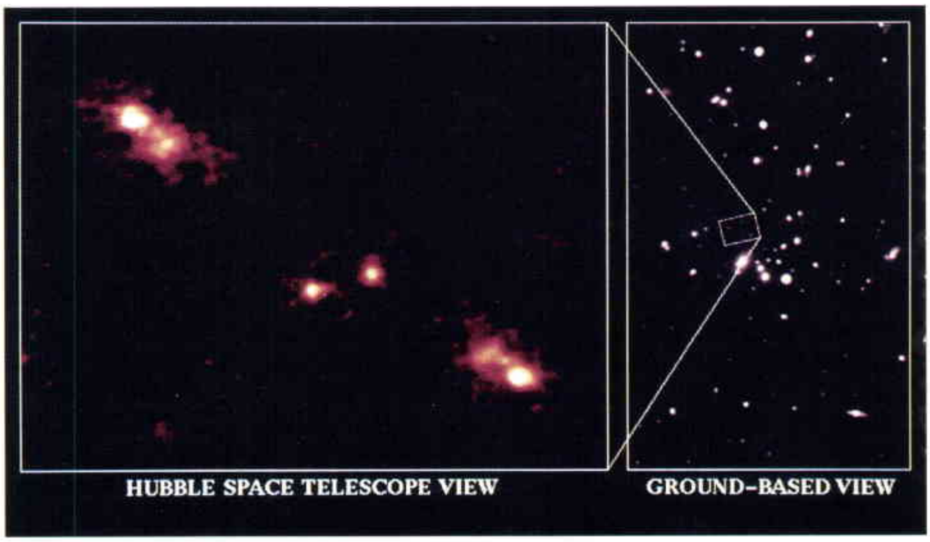
One of the striking aspects of modern astronomy is the search for dark matter. The inner dynamics of galaxies and their star distribution cannot be reconstructed without taking dark matter into account. Astronomers estimate that 90% of the universe is dark matter which does not emit any radiation and therefore can only be detected by indirect methods. The mass of a galaxy can be determined from the light of the stars that form that galaxy, but when investigating the internal motions of galaxies, more mass is needed to explain the gravitational effects being observed. To fully understand the dynamics of galaxies and clusters, the distribution of dark matter has to be taken into consideration.

A promising approach to the search for dark matter involves the use of gravitational lenses. Based on Einstein's theory of relativity, gravitation not only attracts mass but deflects space itself. Therefore, light passing through a gravitational field caused by a massive galaxy or galaxy cluster is bent, with the degree dependent on the mass distribution within this galaxy. This effect can be used to focus light from very distant sources with the help of foreground galaxies. A gravitational lens works like an optical lens and therefore, if the basic properties of that lens are known, the distance of the imaged objects can be calculated and vice versa. The higher the quality of the image is, the more accurate the reproduction of the focusing lens is.

From ground-based observations, Galaxy Cluster AC114 was known to be able to act as a gravitational lens, but the mirror image, taken in one of the first long exposures (six hours) with the HST's Wide Field Camera, has a quality that could never be achieved from a ground-based telescope. Therefore the bending of the gravitational lens, induced by the mass of the foreground galaxy cluster, can be calculated very accurately.

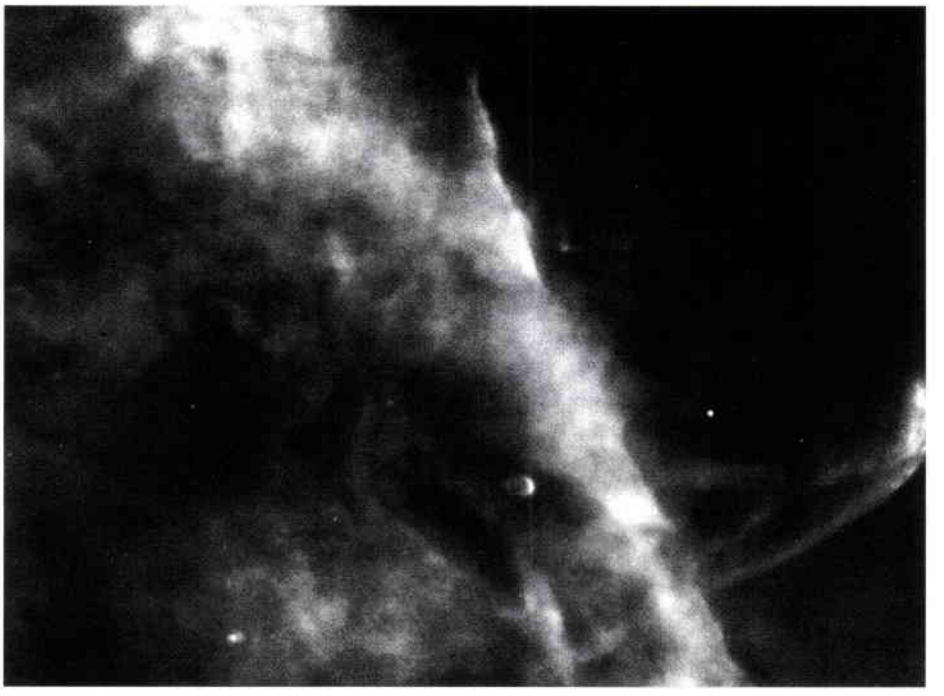
Discovery of a protoplanetary disk around newly-formed stars

The HST has uncovered the strongest evidence yet for the existence of other solar systems in the universe. A group of American scientists used the HST to photograph extended disks of dust around 15 newborn stars in the Orion Nebula. Theory predicts the agglomeration of dust within these disks, and the creation of new planets. The Solar System is considered to have undergone the same evolution. Before the HST discovery, protoplanetary disks had been confirmed around only four stars.



Comparison of the different views of Galaxy Cluster AC114, from HST and from Earth (high-resolution photo of the mirror-image taken with the Wide Field Camera)
(Photo: Richard Ellis (Durham University)/NASA)

According to the present intepretation of the observation, there is evidence that dust surrounding a newborn star has too much spin to be drawn back into the collapsing star and therefore is spread out into a flattened disk around the new 'sun'.



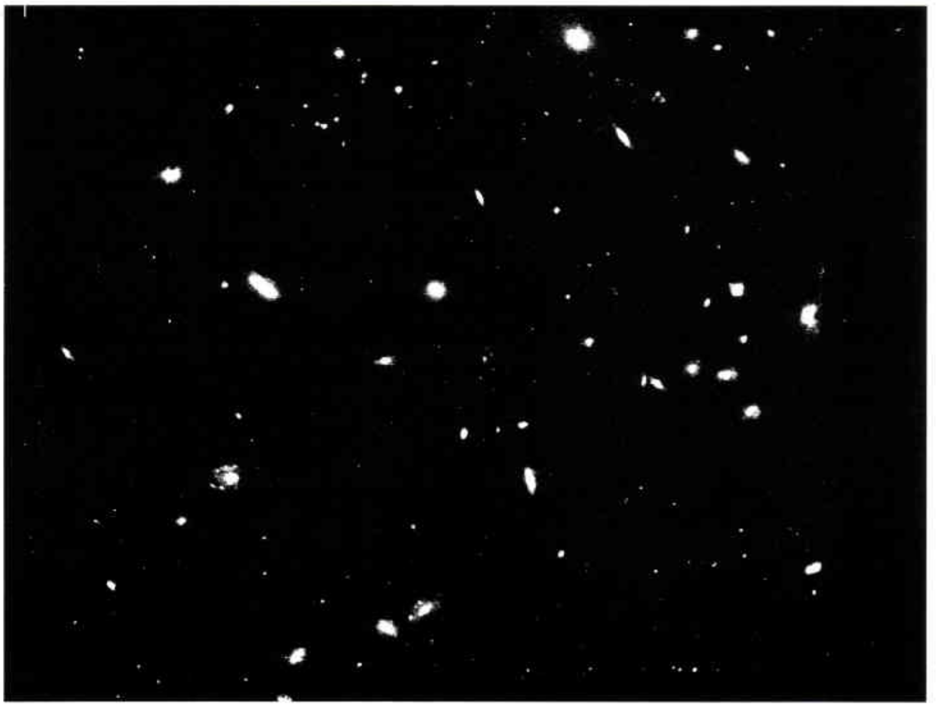
Hypersonic shock wave of dust and gas (lower right), thought to be formed by a beam of material coming out of a newborn star. The HST image (0.5 light years across) is taken at the wavelength of hydrogen and oxygen, two abundant elements in nebula. The plume is only 1500 years old. *(Photo: C.R. O'Dell (Rice University)/NASA)*

Observing the most distant known galaxy

An international team of astronomers used the HST to observe the most distant galaxy known in the universe. The HST revealed a chain of luminous knots in the core of the galaxy. These knots could be giant clusters of stars, each containing about 10 billion stars. The great distance from Earth indicates that 4C41.17 is a very old galaxy, formed only one or two billion years after the Big Bang, the beginning of the observable universe. 4C41.17 is also known as a radio galaxy, and astronomers presume that a massive black hole, rotating in the core of the galaxy, is producing twin particle jets with very high velocity. The photographs taken by the HST are very similar to those made in the radio-spectrum. This similarity suggests that the high velocity particle jets trigger star formation and, if this assumption is correct, the observed knots along the jet paths could be enormous star clusters. Another interpretation is that the light observed by the HST is not emitted by stars along the jet paths, but rather is light from the accretion disk around the black hole. The light would then be scattered in clouds of gas or dust implying that the observed active galactic nucleus might be a quasar.

Observing old galaxy clusters

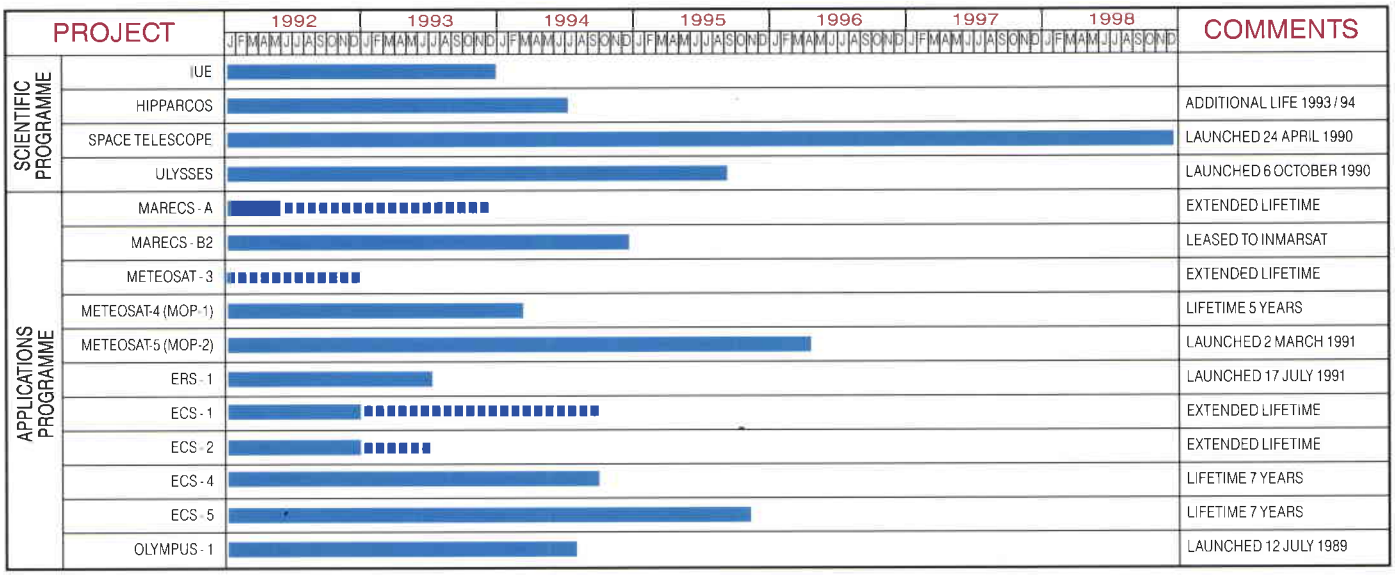
One of the principal goals of the HST is to trace galaxy evolution through direct observations. In the observation of the universe, distance means time: the further away an object is, the older it is. The HST images of the remote galaxy cluster CL 0939+4713 with a distance of four billion light-years and a redshift of z=0.4, existed when the universe was two-thirds of its present age. The HST images, taken with the Wide Field Camera, are sharp enough to distinguish between various forms of spiral galaxies, galaxies in collision, and galaxies merging into single systems. The images confirmed that the abundance of spiral galaxies in very old galaxy clusters was much higher than observed in younger ones, and therefore nearer clusters. These spiral galaxies are believed to have disappeared due to merging, disruption and fading. The HST images provide the first evidence of the environment's influence on the form of a galaxy.



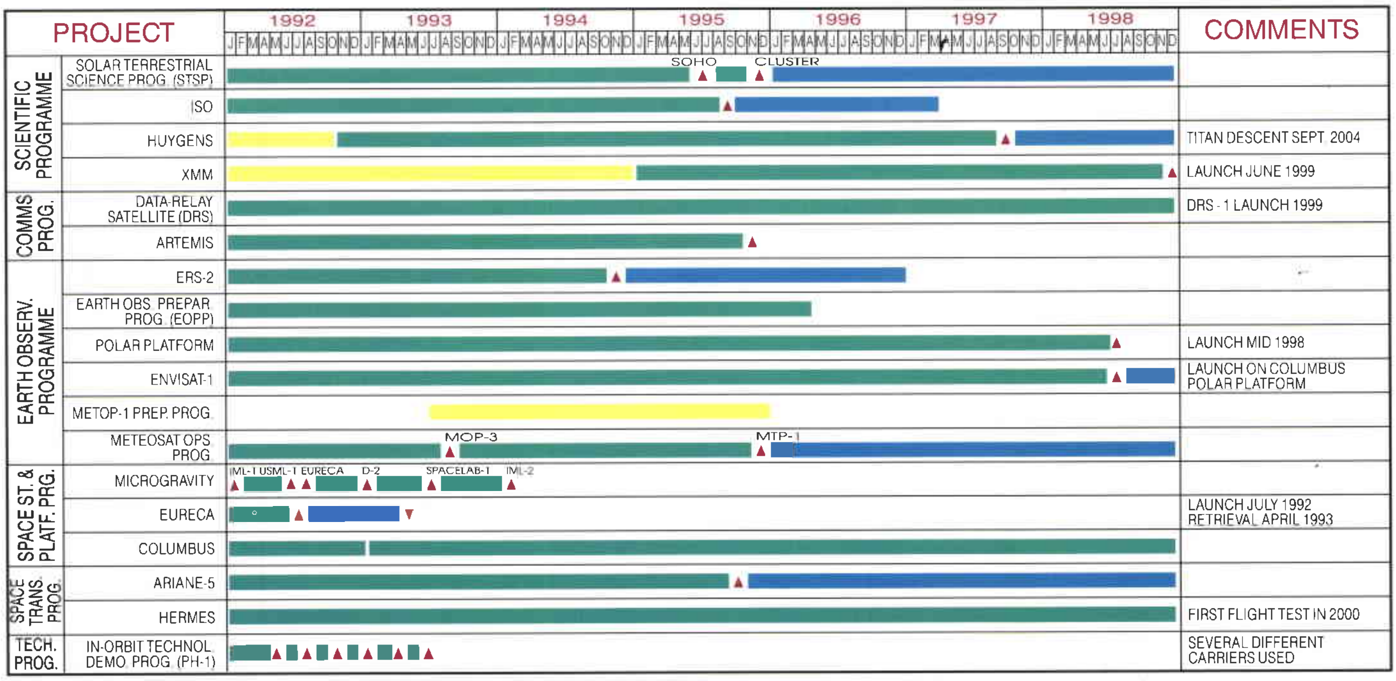
HST image of a portion of the remote galaxy cluster CL 0939+4713 that existed when the universe was two-thirds of its present age. For the first time, the HST high-resolution image allows astronomers to study the shape of galaxies that existed long ago.
(Photo: Alan Dressler (Carnegie Institution)/NASA)

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

Hipparcos

Quelque trois ans et demi après son lancement, le satellite d'astrométrie Hipparcos continue de recueillir des données scientifiques de haute qualité, alors qu'il ne dispose plus que de deux gyroscopes opérationnels sur les cinq d'origine. A la suite de la première panne de gyroscope, l'équipe responsable des opérations à l'ESOC avait mis au point un mode de fonctionnement à deux gyroscopes en collaboration avec le contractant principal, Matra. Le mode de régulation a été mis en route et optimisé au cours d'une 'hibernation' forcée entre août et octobre, à la suite d'une nouvelle série d'anomalies qui seraient dues aux rayonnements très forts auxquels le satellite est exposé sur son orbite fortement elliptique.

Le mode à deux gyroscopes d'Hipparcos diffère sensiblement de la solution adoptée pour le satellite IUE (recours à des données transmises par un suiveur solaire), en ce sens qu'Hipparcos utilise un modèle de bord des couples perturbateurs agissant sur le satellite (essentiellement la pression radiative à l'apogée) pour actualiser les informations d'orientation dérivées du transit des étoiles sur la grille du cartographe stellaire sur la surface focale.

Les observations scientifiques dans ce mode de fonctionnement ont repris à plein régime à la fin octobre 1992, de sorte que la collecte des données se poursuit au-delà de la durée de vie opérationnelle prévue intialement. L'analyse des données se poursuit normalement, ce qui permettra d'achever le catalogue des étoiles deux ans après la mise hors service du satellite.

Ulysse

Un après avoir survolé sans problème la planète Jupiter, la sonde Ulysse et sa charge utile scientifique continuent de fonctionner normalement. Avec un taux moyen de 96%, la récupération des données reste excellente. La part de couverture à débit maximal (1024 bit/s) a constamment dépassé l'objectif nominal de la mission, fixé à un tiers. Il s'agit là d'un résultat particulièrement appréciable étant donné la distance importante – plus de 5 UA (1 unité astronomique = 150 millions de km) – qui a séparé Ulysse de la Terre pendant la majeure partie de 1992.

Après le survol en question, les unités redondantes de la sonde ont fait l'objet d'un contrôle destiné à vérifier si elles avaient été endommagées au cours de leur exposition aux rayonnements intenses de la planète. Il est apparu que toutes les unités fonctionnaient normalement, à l'exception de l'unité terminale centrale de secours (CTU-2) qui fait partie du sous-système de traitement des données. S'il fallait un jour utiliser la CTU-2, sa défaillance compliquerait le fonctionnement du vaisseau spatial et serait préjudiciable pour certaines des données scientifiques. Pour l'heure, toutefois, cette anomalie n'affecte pas la missin scientifique.

Les mesures faites pendant le deux semaines qu'a duré la traversée de la magnétosphère jovienne ont fourni un ensemble de données extrêmement intéressantes, qui nous permet de mieux comprendre les phénomènes à l'oeuvre dans ce plasma complexe et dynamique (voir Bulletin 72). Les premiers résultats du survol ont été publiés dans la revue Science de septembre 1992, et d'autres publications à titre collectif sont en projet. Parallèlement, on procède à l'analyse des données obtenues pendant et après le passage dans le plan de l'écliptique de Jupiter. Depuis le lancement de la sonde voici deux ans et demi, le succès de la mission Ulysse a donné matière à un grand nombre de publications dans la littérature scientifique et de communications lors de conférences internationales.

Une étude initiale a été réalisée pour déterminer s'il est possible, du point de vue technique, de prolonger la mission au-delà de la fin septembre 1995, date à laquelle elle devrait normalement s'achever. Cette étude montre qu'il restera suffisamment d'énergie à bord pour procéder à des activités scientifiques sur la majeure partie d'une deuxième orbite hors de l'écliptique, y compris lors des troisième et quatrième survols des pôles du Soleil en 2000/2001. La principale difficulté technique consistera à maintenir l'hydrazine utilisée pour le système de commande d'orientation à la température voulue. La prolongation de la mission présente un grand intérêt scienifique, car elle permettrait d'étudier les pôles du Soleil pendant une phase du cycle solaire différente de celle qui régnait lors de la mission principale. En effet, les survols des pôles en 1994 et 1995 auront lieu aux alentours du minimum solaire, alors que dans l'hypothèse d'une prolongation de la mission, la phase aux latitudes élevées se déroulerait aux alentours du maximum solaire.

A la mi-1993, la sonde se trouvera à 30° sud de l'équateur du Soleil et l'on s'attend à observer, au cours des mois à venir, les premiers signes nets d'une incidence de la latitude sur les données d'Ulysse.

ISO

Instruments scientifiques

Toutes les électroniques de vol des instruments scientifiques ont été intégrées sur la plate-forme supérieure du module de servitude et subissent actuellement les essais. Les modèles de vol des unités du plan focal en sont aux derniers essais; ils devront pouvoir être montés sur le modèle de vol du télescope au deuxième trimestre de l'an prochain.

ISO

Hipparcos

The Hipparcos astrometry satellite continues to collect high-quality scientific data, nearly three and a half years after launch, albeit with only two of its original five gyros now operational. A two-gyro operating mode had been developed by the ESOC operations team in collaboration with the satellite's prime contractor, Matra, following the first gyro failure. This control mode was implemented and optimised during a forced 'hibernation' between August and October 1992 following a series of further gyro anomalies, presently believed to result from the very high radiation fluences experienced by the satellite in its revised highly elliptical orbit.

The Hipparcos two-gyro mode is quite different from the solution adopted in the case of IUE (where information from a Sun sensor is used) in that Hipparcos employs an onboard model of the perturbing torques acting on the satellite (predominantly radiation pressure at apogee) to update attitude information derived from star transits across the star-mapper grid in the focal surface.

Full scientific operations under the two-gyro control resumed at the end of October 1992, so that data collection is now extending beyond the originally foreseen operational lifetime. Data analysis is proceeding well, consistent with the final Star Catalogue's completion two years after the end of the satellite operations.

Ulysses

One year after its successful flyby of the planet Jupiter, the Ulysses spacecraft and its scientific payload continue to function well. Data coverage remains excellent, exceeding 96% on average. The fraction of coverage at maximum bit rate (1024 bps) has been consistently above the nominal one-third target for the mission. This is a particularly good achievement given Ulysses' great distance – in excess of 5 AU (1 Astronomical Unit = 150 million km) – from the Earth throughout most of 1992.

Following the flyby, the redundant spacecraft units were checked to see if they had sustained damage during the passage due to Jupiter's intense radiation environment. All were found to work nominally, with the exception of the backup Central Terminal Unit (CTU-2), part of the Data-Handling Subsystem. If it should become necessary to use CTU-2 at some time in the future, the fault would complicate the spacecraft operations and adversely affect some of the scientific data. At present, however, this anomaly has no impact on the scientific mission.

The measurements made during the two-week flight through the Jovian magnetosphere constitute a highly valuable data set that is helping to shed light on the workings of this complex and dynamic plasma environment (see also Bulletin 72). Initial results from the flyby appeared in the scientific journal *Science* in September 1992, and further coordinated publications are planned. In parallel, analysis of the data obtained during the in-ecliptic and post-Jupiter phases of the mission is in progress. The success of the Ulysses mission to date is reflected in the large number of papers that have been published in the scientific literature or presented at international conferences during the two and a half years since the spacecraft was launched.

An initial study has been performed to evaluate, from a technical standpoint, the feasibility of extending the mission beyond its nominal termination at the end of September 1995. The results of this study indicate that there will be sufficient onboard power to support scientific operations for the majority of a second out-of-ecliptic orbit, including third and fourth polar passes in 2000/2001. The major technical constraint concerns the maintenance of an adequate thermal environment for the hydrazine used in the attitude-control system.

The scientific interest in an extended mission is particularly high because it would afford the opportunity to study the polar regions of the Sun during the opposite phase of the solar cycle to the prime mission. The 1994/95 polar passes will occur near solar minimum, whereas an extended mission would have its high-latitude phase near solar maximum.

By mid-1993, the spacecraft will be 30° south of the Sun's equator, and the coming months are expected to reveal the first clear signs of latitude-dependent effects in the Ulysses data.

ISO

Scientific instruments

All flight-model electronic units of the scientific instruments have been integrated onto the service module's upper platform and are being tested. The flight-model focal-plane units are in final testing; these are needed for installation on the flight-model telescope in the second quarter of next year.

Good progress is also being made in the testing of the flight-spare units of the four scientific instruments.

Satellite

The payload-module development model has been used to perform cryo-servicing trials simulating the final operations to be conducted on the launch vehicle. This develoment model will be used to demonstrate a bake-out procedure and will then be put into storage.

Good progress has been made towards resolving the problems of the flight-model telescope and the liquid-helium valves for the payload module. The telescope integration is proceeding satisfactorily. Two types of design for the liquid-helium valves are in qualification testing, and another valve type from a different supplier is in development testing. It is intended to select the most suitable valve type early next year for installation in the payload module. Integration of the flight-model payload module is planned to start in January 1993.

The flight-model service module now has its power, data-handling and radio-frequency subsystems integrated. Tests on these subsystems have shown good results, with only minor corrections to be made to two units. Further testing of the service module awaits delivery of the attitude-control subsystem, which is in final testing prior to delivery to the prime contractor in early 1993.

The overall project schedule has been reviewed and measures introduced to make it less sensitive to late delivery of the valves and telescope. This assessment of the schedule, remaining risks

Les essais des rechanges aux normes de vol des quatre instruments scientifiques avancent également de façon satisfaisante.

Satellite

Le modèle de développement du module de charge utile a été utilisé pour des essais de ravitaillement cryogénique simulant les dernières opérations à exécuter, le satellite étant sur le véhicule lanceur. Ce modèle de développement servira à la démonstration d'une procédure d'étuvage avant d'être entreposé.

La solution des problèmes posés par le modèle de vol du télescope et les vannes à hélium liquide pour le module de charge utile est en bonne voie. L'intégration du télescope progresse de façon satisfaisante. Deux types de vannes subissent les esais de qualification et un autre venant d'un fournisseur différent en est actuellement aux essais de développement. On a l'intention de sélectionner au début de l'an prochain le type de vanne convenant le mieux pour le monter dans le module de charge utile. Il est prévu de commencer l'intégration du module de charge utile de vol en janvier 1993.

Le modèle de vol du module de servitude est maintenant pourvu de ses sous-systèmes d'alimentation en énergie, de gestion des données et radio-fréquence, qui lui ont été intégrés. Les essais auxquels ont été soumis ces sous-systèmes ont donné de bons résultats, et seules quelques très légères corrections devront être apportées à deux unités. On attend maintenant pour les autres essais du module de servitude la livraison du sous-système de commande d'orientation, qui subit ses derniers essais avant d'être livré au maître d'oeuvre début 1993.

Le calendrier d'ensemble du projet a été revu et des mesures adoptées pour limiter les incidences de la livraison tardive des vannes et du télescope. Cette évaluation du calendrier, des risques restants et des fenêtres de lancement possibles a conduit l'équipe projet à viser désormais une fenêtre de lancement se situant au cours de l'hiver 1995.

Secteur sol

La préparation des opérations en vol du véhicule spatial avance de façon satisfaisante, mais celle des opérations scientifiques donne lieu à préoccupation. On examine la situation, à la recherche de simplifications et d'un contrôle plus étroit de toutes les interfaces.

Les échanges de vues se poursuivent entre l'ESA, le Japon et la NASA sur une coopération possible qui permettrait d'accroître les observations scientifiques d'ISO grâce à la fourniture d'une deuxième station au sol.

Huygens

La revue de conception système (SDR) de la sonde Huygens a eu lieu comme prévu à la mi-octobre. La Commission, réunie chez le maître d'oeuvre, a examiné l'état d'avancement de la conception détaillée et de la préparation des activités de développement de la sonde, pour conclure que la situation d'ensemble était satisfaisante et que le projet pouvait passer à la phase de mise au point et de fabrication.

Cependant, si la base de référence du système a été globalement approuvée, plusieurs sujets de préoccupation n'en ont pas moins été relevés par la Commission qui a prescrit des mesures pour y remédier. On citera notamment les interfaces entre la structure en aluminium du décélérateur de la sonde et le revêtement de protection thermique, les densités de conditionnement et d'installation d'équipements à bord et les garanties de bon fonctionnement de la sonde après ses très longues phases de croisière et de sommeil. La conception du décélerateur a maintenant été remaniée – il sera fabriqué en matériaux en fibre de carbone – et des études sont en cours pour analyser plus avant les autres questions et apporter la démonstration d'une situation satisfaisante.

En liaison avec la SDR, l'appel d'offres relatif à la phase-C/D industrielle a été conduit. Evaluation et négociation sont en cours en vue de parvenir à une base de référence contractuelle et technique solide pour la soumission de propositions contractuelles au Comité de la politique industrielle (IPC) de l'Agence lors de sa réunion de mars 1993.

Pour assurer la continuité des travaux, le contrat limité de phase-C/D anticipée a été prolongé de façon à couvrir l'intervalle entre la SDR clôturant officiellement la phase-B et la fin mars 1993 pour laquelle est attendu l'accord de l'IPC sur le contrat de phase-C/D.

Artemis

La phase de développement proprement dite du satellite Artemis a été approuvée par le Comité de la politique industrielle de l'Agence en septembre 1992; les activités industrielles démarrent maintenant. Artemis fournira une capacité de télécommunications de pointe avec les mobiles terrestres et complètera la charge utile EMS que doit emporter le satellite Italsat-F2. Il offrira également des possibilités de relais de données préopérationnel en bande S, en bande Ka et aux fréquences optiques.

La réalisation du terminal de relais de données optique qui doit être embarqué à bord de Spot-4 s'est poursuivie et le modèle électrique du terminal sera livré sous peu pour des essais sur le modèle d'identification de Spot-4.

Spot-4 emportera également un terminal de relais de données opérant dans la bande S dont la revue critique de conception a été menée à bien.

DRS

Le Conseil de l'ESA siégeant au niveau ministériel à Grenade (E) en novembre a approuvé le programme DRS; les études devant conduire à l'approvisionnement des équipements du premier satellite DRS sont actuellement lancées.

ERS

ERS-1

Le suivi régulier d'ERS-1 confirme l'excellent fonctionnement de la plate-forme et de l'instrumentation du satellite. La stabilité des instruments est telle que les mesures actuelles peuvent être rapprochées des résultats de la phase and launch-window possibilities has led the project to aim now for a winter-1995 launch.

Ground segment

Spacecraft flight operations preparations are proceeding satisfactorily, but the preparations for the science operations are a matter of concern. The situation is under review to identify simplifications and tighten control over all interfaces.

Discussions continue between ESA, the Japanese and NASA on possible cooperation which would lead to an increase in ISO's science observations via the provision of a second ground station.

Huygens

The System Design Review (SDR) for the Huygens Probe was held in mid-October as planned. The Review Board, meeting at the prime contractor's premises, examined the status of the detailed design and the preparations made for Probe development activities. It concluded that a satisfactory overall situation had been achieved and that the project could proceed to the development and manufacturing phase.

Notwithstanding the overall acceptance of the system baseline, a number of areas of concern were identified by the Review Board and actions were assigned to resolve them. Of particular concern were the interfaces between the Probe's aluminium decelerator structure and the thermal-protection medium, accommodation and packaging densities onboard the Probe, and the guarantees for successful Probe operations following the very long cruise and dormancy phases. The decelerator has now been redesigned to be built using carbon-fibre materials, and studies are under way to analyse further the other issues and provide demonstrations of satisfactory status.

In conjunction with the SDR, the tender action for industrial Phase-C/D was conducted. Evaluation and negotiations are under way with the intention of achieving a solid contractual and technical baseline enabling submission of contractual proposals to the Agency's Industrial Policy Committee (IPC) at its meeting in March 1993.

To ensure continuity of work, the limited advanced Phase-C/D contract has been extended to provide cover for the period between the SDR, when Phase-B formally terminated, and the end of March 1993, when IPC approval of the Phase-C/D contract is anticipated.

Artemis

The full development phase for the Artemis satellite was approved by the Agency's Industrial Policy Committee (IPC) in September 1992, and the industrial activities are now commencing. Artemis will provide an advanced land-mobile communication capacity and will supplement the EMS payload to be carried on the Italsat-F2 satellite. It will also provide a pre-operational data-relay capability at S-band, Ka-band and at optical frequencies.

The development of the optical data-relay terminal to be carried on Spot-4 has continued and the electrical model of the terminal will be delivered shortly for testing on the Spot-4 engineering model.

Spot-4 will also carry a data-relay terminal operating at S-band, and its Critical Design Review has been successfully completed.

DRS

The ESA Council Meeting at Ministerial Level in Granada (E) in November approved the DRS Programme, and studies that will lead to the procurement of the equipment for the first DRS satellite are now being started.

DRS

ERS

ERS-1

The regular monitoring of ERS-1 confirms the excellent performance of the satellite platform and its instrumentation. The instrument stability is such that present measurements can be referenced to commissioning-phase results without any need for corrections.

A parity error in the platform's onboard computer memory degraded the availability of the satellite from mid-July until early-September, when the faulty memory component was isolated and bypassed. Since then, the availability of the platform and instrumentation has been fully restored to its previous level of about 99%.

With solar activity continuing to decrease, the interval between manoeuvres for maintaining the ±1 km orbit repetitivity is now approaching 1 month, compared to the 7 day interval at the beginning of the mission.

The First ERS-1 Symposium held in Cannes on 4–6 November 1992 was attended by more than 400 participants and demonstrated the great interest and motivation of the scientific community, as well as highlighting very promising preliminary results. A live demonstration of reception of Synthetic Aperture Radar Fast-Delivery (SAR FD) low-resolution *de recette sans qu'aucune correction soit nécessaire.*

Une erreur de parité dans la mémoire de l'ordinateur de bord équipant la plate-forme a amoindri la disponibilité du satellite de la mi-juillet au début de septembre, où l'on a pu isoler le composant mémoire défectueux et le mettre hors circuit. Depuis lors, la plate-forme et ses instruments ont retrouvé toute leur disponibilité antérieure se situant à un taux d'environ 99%.

L'activité solaire continuant à décliner, l'intervalle entre les manoeuvres visant à maintenir l'orbite à ±1 km de l'orbite nominale est maintenant de près d'un mois, au lieu des 7 jours du début de la mission.

Le premier symposium ERS-1 qui s'est déroulé à Cannes du 4 au 6 novembre 1992 a rassemblé plus de 400 participants, témoignant du vif intérêt et de la motivation de la communauté scientifique mais aussi apportant des résultats préliminaires très prometteurs. La démonstration en direct de la réception des images à faible résolution, à livraison rapide (FD), du radar à synthèse d'ouverture (SAR) ainsi que des produits FD des instruments à faible débit (LBR) à l'échelle du globe a suscité un grand intérêt de la part des utilisateurs représentés au symposium, montrant la nécessité de promouvoir tous les services dont pourraient bénéficier les utilisateurs.

L'élaboration de produits SAR FD s'est poursuivie dans les stations de l'ESA et un volume important de données archivées a été mis à la disposition des utilisateurs pour répondre à leurs besoins en produits FDC (copies à livraison rapide). En parallèle, l'élaboration des produits FD des instruments à faible débit a été exécutée dans les stations désignées conformément aux plans. La distribution des données SAR FD par l'intermédiaire du réseau de diffusion de données à large bande (BDDN) s'est poursuivie à titre expérimental en attendant que le système passe au plein régime opérationnel.

En ce qui concerne les activités 'en différé', les données de la période allant jusqu'à septembre 1992 ont été transcrites à Fucino (Italie) et réacheminées sur disques optiques à destination des installations de traitement et d'archivage (PAF) de France et du Royaume-Uni. Des produits SAR et LBR en différé ont été confectionnés dans les installations PAF en réponse aux demandes des utilisateurs, qui comprennent des responsables de recherches (PI) et des projets pilotes sélectionnés par l'ESA ainsi que des utilisateurs commerciaux, via le consortium ERSC.

Le document ESA SP-1146 sur le système ERS-1 a été distribué aux utilisateurs.

La liaison directe par courrier électronique (service OMNET) entre l'ESRIN et les utilisateurs, le 'Bulletin Board' ERS-1 précédemment en service, a été rétablie et fonctionnera de façon régulière.

Les distributeurs du consortium ERSC se sont réunis à l'ESRIN (I) en octobre. Les principaux sujets abordés ont été le système ERS-1 et ses aspects opérationnels, ses produits et ses applications, ainsi que les services de mise en valeur du contenu des produits. Des représentants de tous les grands pays européens ainsi que d'Etats d'Europe de l'Est et d'Afrique du Nord ont assisté à cette réunion.

ERS-2

Le programme ERS-2 a continué de se dérouler conformément au calendrier. L'instrument AMI a été livré et son intégration à la charge utile a commencé. Les essais de recette du RA et de l'IDHT sont en voie d'achèvement et ces instruments seront livrés prochainement. Le radiomètre optique de l'ATSR-2 a été livré à l'installation d'étalonnage et le cycle des essais de recette du radiomètre à hyperfréquence est bien engagé.

ERS-1 image (SAR) of Lanzarote, Canary Islands

Bien que les réservoirs à ergol et les propulseurs de la plate-forme aient posé quelques problèmes, on a pu maintenir la date de livraison initialement prévue en réaménageant le détail du calendrier.

Le prototype de l'instrument de surveillance de l'ozone à l'échelle du globe (GOME) continue de bien avancer; le banc optique est d'ores et déjà intégré et l'unité électronique en est aux derniers stades de la recette. L'approvisionnement des éléments du modèle de vol est très avancé et l'autorisation de passer à la fabrication devrait être donnée sous peu.

Météosat

Le satellite Météosat-4 a continué d'assurer le service opérationnel de sa position orbitale à 0° de longitude, tandis images and global low-rate FD products attracted strong interest from the user community represented at the Symposium, demonstrating the need to promote all potential user services.

SAR FD product generation at ESA stations has continued, with a consistent volume of archived data being put at the users' disposal for their FDC (Fast Delivery Copy) product needs. In parallel, the generation of Low-Bit-Rate FD products has been carried out at the designated stations according to plan. The dissemination of SAR FD data via the Broad-band Data Dissemination Network (BDDN) has continued on an experimental basis whilst awaiting the system's transition to full operations.

Turning to 'offline' activities, data through September 1992 have been transcribed at Fucino (I) and forwarded on optical disks to the Processing and Archiving Facilities (PAFs) in France and the UK. Offline SAR and LBR products have been generated at the ERS PAFs in accordance with user requests. Users include Principal Investigators (PIs) and Pilot Projects selected by ESA, as well as commercial users via the ERSC Consortium.

The ERS-1 System document (ESA SP-1146) has been distributed to the user community.

The direct ESRIN–users link via electronic mail (OMNET service), active in the past as the 'ERS-1 Bulletin Board', has been resumed and will operate on a regular basis.

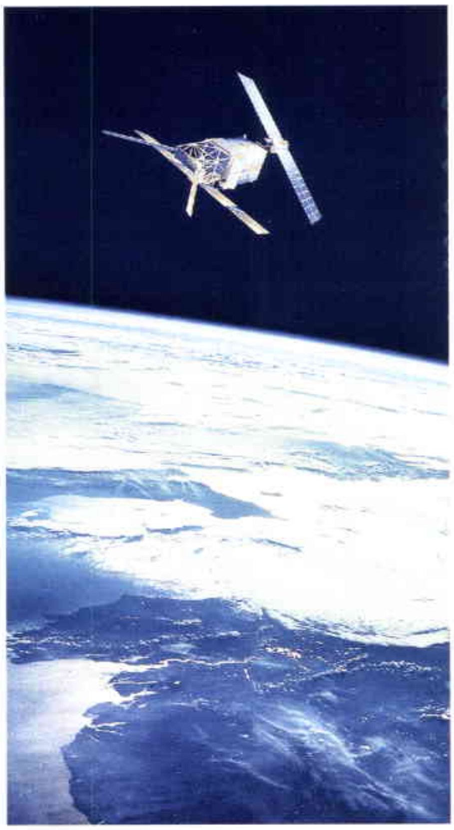
A meeting of the ERSC Consortium Distributors took place at ERIN (I) in October. The major topics considered were the ERS-1 System and its operational aspects, products and applications, as well as product-enhancement services. The meeting was attended by representatives from all of the major European Countries as well as Eastern Europe and North African states.

ERS-2

The ERS-2 Programme has continued to progress according to schedule. The AMI instrument has been delivered and payload-integration activities have commenced. The RA and IDHT are nearing completion of their acceptance testing and will be delivered in the near future. The ATSR-2 optical radiometer has been delivered to the calibration facility; the microwave radiometer is part way through its acceptance-test cycle.

Whilst some problems have occurred with the platform thrusters and propellant tanks, detailed schedule rearrangements have made it possible to maintain the original delivery planning.

The prototype of the Global Ozone Monitoring Experiment (GOME) instrument has continued to progress well, with the optical bench already integrated and the electronics unit in the final stages of acceptance. Procurement of elements for the flight model is at an advanced stage, and release of manufacture is expected shortly.



ERS-1

Meteosat

Meteosat-4 has continued to provide the operational service from its orbital position at 0° longitude, whilst Meteosat-3 has provided imaging of the Western Atlantic from 50°W. Meteosat-5 remains as an in-orbit standby at 3°W.

The subsystems have been mechanically integrated on MOP-3, the last spacecraft of the Meteosat Operational Programme series, and performance testing has commenced. Its launch by an Ariane vehicle is scheduled for the end of 1993.

Manufacture of the subsystems for the Meteosat Transition Programme satellite to be procured for Eumetsat has continued. Launch is foreseen in the last quarter of 1995.

Earthnet

The behaviour of the JERS-1 payload instrumentation (OPS and SAR instruments) appears to be below normal, as both instruments are reported to be experiencing problems. Nevertheless, OPS and SAR data have been routinely acquired at Fucino (I) since October, whilst Kiruna (S) and Tromsø (N) have recorded OPS and SAR data, respectively.

The SAR processing software has been installed and tested at ESRIN and Fucino in Italy. Its installation at DLR in Germany is nearly complete, and is planned to occur in 1993 for Tromsø.

In anticipation of the launch of Landsat-6, scheduled for early 1993, testing of the Enhanced Thematic Mapper (ETM) processing system currently under development will be carried out using Landsat-4/5 TM data.

Landsat-5 and MOS-1/1b data-product generation has continued.

MOS data acquisition was discontinued at the Fucino and Kiruna stations at the end of October to allow routine JERS-1 operations. The Maspalomas station still receives MOS data and has also resumed the acquisition and processing of Spot data on behalf of Spotimage.

NOAA-11 (afternoon) and NOAA-12 (morning) data have been routinely acquired by the Earthnet coordinated Tiros Network. The collection of AVHRR data, started in April 1992 for the NASA – NOAA – ESA joint 'One Kilometre Resolution Global Data Set' project, has continued.

que le satellite Météosat-3, à poste par 50° de longitude ouest, fournissait des images de la zone ouest de l'Atlantique. Le satellite Météosat-5 reste en position de réserve en orbite par 3° de longitude ouest.

Les sous-systèmes du satellite MOP-3, le dernier de la série du programme Météosat opérationnel, ont franchi le stade de l'intégration mécanique et les essais de fonctionnement ont commencé. Le lancement de MOP-3 par une fusée Ariane est programmé pour fin 1993.

La fabrication de sous-systèmes du satellite du programme de transition Météosat à approvisionner pour Eumetsat s'est poursuivie. Le lancement est prévu au dernier trimestre de 1995.

Earthnet

Les instruments (OPS et SAR) de la charge utile du satellite JERS-1 semblent présenter un comportement de qualité inférieure à la normale, des problèmes étant signalés pour tous deux. Les données de l'OPS et du SAR n'en ont pas moins été captées de façon régulière à Fucino (I) depuis octobre, les stations de Kiruna (S) et Tromsø (N) ayant pour leur part enregistré les données de l'OPS pour l'une et du SAR pour l'autre.

Le logiciel de traitement des données SAR a été mis en place et testé à l'ESRIN et à Fucino en Italie. Son installation à la DLR, en Allemagne, est presque achevée; pour Tromsø, elle est prévue pour 1993.

En prévision du lancement du satellite Landsat-6 programmé pour début 1993, les essais du système de traitement des données de l'instrument de cartographie thématique améliorée (ETM) en cours de mise au point seront effectués en utilisant les données TM de Landsat-4/5.

L'élaboration des produits de données Landsat-5 et MOS-1/1b s'est poursuivie.

L'acquisition des données MOS a été interrompue dans les stations de Fucino et Kiruna fin octobre au profit d'opérations JERS-1 régulières. La station de Maspalomas reçoit toujours les données MOS et elle a repris l'acquisition et le traitement des données Spot pour le compte de Spotimage.

Le réseau Tiros coordonné par Earthnet a assuré l'acquisition régulière des données de NOAA-11 (après-midi) et NOAA-12 (matin). La collecte des données AVHRR, commencée en avril 1992 pour le projet commun NASA-NOAA-ESA qui vise la production d'un ensemble de données à l'échelle du globe offrant une résolution de 1 km, s'est poursuivie.

Les produits de données de niveau 1–2 du projet OCEAN ont été distribués aux chercheurs.

Les équipements qui permettront de recevoir les données SAR d'ERS-1 par la station de Bangkok dans le cadre du projet ASEAN ont été approvisionnés et leur livraison est en cours. Contrat a été passé pour l'approvisionnement du processeur SAR.

Les activités Earthnet relatives au secteur sol de la charge utile d'ERS-1 sont traitées plus haut sous la rubrique ERS-1.

EOPP

Aristoteles
Le programme Aristoteles n'ayant pas été inscrit dans le Plan à long terme de l'Agence, l'Exécutif a proposé au Conseil de poursuivre les activités au niveau minimal nécessaire au maintien du programme (qui correspond à la phase-B). Entre-temps, toutes les activités industrielles nécessaires pour éviter l'interruption du programme ont suivi leur cours.

Météosat de deuxième génération
A la suite des Résolutions adoptées par le Conseil de l'ESA siégeant au niveau ministériel à Grenade et des résultats de la réunion du Conseil Eumetsat qui s'est également déroulée en novembre 1992, la préparation des activités visant à obtenir l'approbation de ce programme à conduire en commun avec Eumetsat se trouve maintenant bien engagée. Le programme prévoit le développement par l'ESA du premier satellite de cette série nouvelle, à lancer en l'an 2000.

En parallèle, l'industrie a continué à définir et affiner dans le cadre d'activités de phase-A la conception du satellite et de la charge utile.

Missions sur orbite terrestre basse
Les ministres ayant décidé de scinder le programme POEM en deux éléments, Envisat-1 et Metop-1, on prépare les études de phase-A de Metop-1 dans le cadre de l'EOPP. Les travaux se poursuivent dans le même temps sur la définition d'instruments d'avant-garde.

Campagnes
La période d'observation de l'expérience pilote Hydrologie-Atmosphère (HAPEX) sur le Sahel s'est achevée; les expérimentateurs reçoivent actuellement les données. La distribution des données de la campagne SAREX est pratiquement terminée.

Un atelier sur les résultats de la campagne ELAC-90 (lidar atmosphérique) s'est déroulé en octobre 1992.

Les campagnes en cours de préparation sont axées sur le lidar 'vents' à effet Doppler et une campagne mettant en oeuvre des instruments multiples, essentiellement tournée vers les glaces et les forêts et faisant appel à des observations associant SAR, spectromètre imageur et détecteur passif à hyperfréquence.

Plate-forme polaire

Le Conseil de l'ESA siégeant au niveau ministériel à Grenade a confirmé la réalisation de la plate-forme polaire, qui servira pour les deux missions Envisat et Metop. Les impératifs multimissions seront revus à la baisse pour se limiter aux besoins de ces deux missions.

La revue de conception préliminaire (PDR) de la plate-forme polaire au niveau système a été menée à bien début novembre, confirmant la validité de la base de référence technique de la plate-forme par rapport aux impératifs multimissions initiaux. Quelques points exigeant la prise de mesures spéciales ont toutefois été relevés (phase LEOP, bande Ka).

Après la PDR, les activités se sont

OCEAN Project Level 1-2 data products have been distributed to researchers.

The acquisition equipment for ERS-1 SAR data at the Bangkok station within the ASEAN Project has been procured and delivery is in progress. The contract for the procurement of the SAR processor has been awarded.

Earthnet's activities on the ERS-1 payload ground segment are reported above, under ERS-1.

EOPP

Aristoteles
Given that Aristoteles was not included in the Agency's Long-Term Plan, the Executive proposed to Council to proceed with the minimum effort required to maintain the programme (this corresponds to the Phase-B). Meanwhile all industrial activities necessary to maintain the programme have continued.

Meteosat Second Generation
Following the adoption of the Resolutions by the ESA Council Meeting at Ministerial Level in Granada and the results of the Eumetsat Council Meeting which also took place in November 1992, the preparation of activities to obtain approval for this joint programme with Eumetsat is now well advanced. The programme calls for ESA to develop the first of this new series of satellites for launch in the year 2000.

In parallel, industry has continued, through Phase-A activities, to define and refine the satellite and payload designs.

Low-Earth-orbit missions
Following the decision of the Ministers to split the POEM Programme into two elements, Envisat-1 and Metop-1, the Phase-A studies for Metop-1 are being prepared within the EOPP. Meanwhile, work on defining advanced instruments has continued.

Campaigns
The observation period of the Hydrological Atmospheric Pilot Experiment (HAPEX) over the Sahel has been completed and the data is now being distributed to experimenters. Data distribution from the SAREX campaign is nearly complete.

A workshop on the ELAC-90 atmospheric lidar campaign results was held in October 1992.

The campaigns currently being prepared focus on Doppler Wind Lidar and a multiple sensor campaign aimed primarily at ice and forestry using a mixture of SAR, imaging spectrometers and passive microwave observations.

Polar Platform

The Polar Platform's development was confirmed as an outcome of the ESA Council Meeting at Ministerial Level in Granada. It will support both the Envisat and Metop missions. The multi-mission requirements will be de-scoped to those necessary to support these two missions.

The Polar Platform system Preliminary Design Review (PDR) was successfully completed in early November. The review confirmed the soundness of the Platform technical baseline against the initial multi-mission requirements. A few issues were, however, identified which merit special action (LEOP, Ka-band).

Following the PDR, the Polar Platform activities have concentrated on updating the requirements and consolidating the configuration required for the Envisat-1 mission. A number of technical issues have continued to receive attention (e.g. LEOP operations, solar array, Ka-band subsystem, shocks induced by separation).

The full-scale Polar Platform configuration model is now being used for the integration of payload mock-ups to verify interfaces and accommodation.

The RF mock-up of the Platform, complete with representative antennas, has successfully completed a test campaign for measuring antenna coupling factors.

Manufacture of thruster and tanks parts for the Service Module has started. The secondary-structure manufacturing drawing has been completed, together with the overall assembly plan. A study to define separation shocks better has also been completed. Solar-array breadboarding of critical parts has continued.

The Payload Module activities have progressed and a requirement and design simplification of the Ka-band subsystem has been initiated. The thermal and tape recorder PDRs have been held successfully.

AIV activities have concentrated on the verification database and on updating design and development/AIT plans.

All high-reliability parts for the Service Module have been ordered and 60% have already been delivered. Long-lead items for the Payload Module electrical subsystems have also been ordered.

The Interface Control Document from Arianespace that formalises interfaces with Ariane-5 has been issued and is under review.

Work has progressed towards the definition of the ground segment for command and control. A draft Mission Implementation Requirements Document has been established.

Increased coordination between POEM and Polar Platform activities has taken place. In particular, Agency internal studies have been conducted in order to define the characteristics of the Polar Platform for the Envisat-1 mission.

POEM-1

Preparatory Programme
System and instrument Phase-B studies
Extensions of Phase-B studies for ASAR, GOMOS and ASCAT continued, with emphasis on detailing the design and on breadboarding critical equipment. Otherwise, the mission prime activities for Phase-B are complete.

MIMR instrument
The Phase-B design review of MIMR has been held.

Ground segment
The contract was kicked-off in June. Logica have defined a contractor reference architecture and have produced a System Requirements Document intended to serve as a reference for all subsequent activities. Some limited redirection took place to reflect the outcome of the Ministerial Council in Granada.

concentrées sur la mise à jour des impératifs et la consolidation de la configuration requise pour la mission Envisat-1. Un certain nombre de questions techniques ont continué de retenir l'attention (par exemple: opérations de la phase LEOP, réseau solaire, sous-système en bande Ka, chocs induits par la séparation).

La maquette en vraie grandeur de la plate-forme polaire sert maintenant à l'intégration des maquettes de charge utile en vue de vérifier leurs interfaces et leur installation.

La maquette RF de la plate-forme, complètement équipée d'antennes représentatives, a subi avec succès une campagne d'essais ayant pour objet de mesurer les facteurs de couplage d'antennes.

La fabrication des propulseurs et des pièces de réservoirs destinés au module de servitude a démarré. Les plans de fabrication de la structure secondaire ont été achevés, ainsi que le plan de montage général. Une étude visant à mieux définir les chocs à la séparation a également été faite. Le montage sur table de pièces critiques du réseau solaire s'est poursuivi.

Les activités relatives au module de charge utile ont avancé et on s'est attaqué à la simplification des impératifs et de la conception du sous-système en bande Ka. Les PDR du système de régulation thermique et de l'enregistreur sur bande se sont également déroulées avec succès.

Les activités d'assemblage, d'intégration et de vérification (AIV) ont été centrées sur la base de données de vérification et sur la mise à jour de la partie AIT des plans de conception et de réalisation.

Toutes les pièces à haut degré de fiabilité du module de servitude ont été commandées et 60% d'entre elles ont déjà été livrées. Commande a également été passée pour les articles à long délai de livraison des sous-systèmes électriques du module de charge utile.

Le document de contrôle d'interfaces d'Arianespace officialisant les interfaces avec Ariane-5 a été publié; il est à l'examen.

Les travaux de définition du secteur sol dans le domaine commande et contrôle ont avancé. Le projet d'un document sur les impératifs de mise en oeuvre de la mission a été établi.

La coordination a été renforcée entre les activités POEM et Plate-forme polaire. L'Agence a notamment conduit des études internes en vue de définir les caractéristiques de la Plate-forme polaire pour la mission Envisat-1.

POEM-1

Programme préparatoire

Etudes de phase-B au niveau système et instruments

Les prolongations des études de phase-B sur les instruments ASAR, GOMOS et ASCAT se sont poursuivies, l'accent étant mis sur le détail de la conception et le montage sur table d'équipements critiques. Sinon, les activités du maître d'oeuvre mission pour la phase-B sont terminées.

Instrument MIMR

La revue conceptuelle de phase-B du MIMR a eu lieu.

Secteur sol

Le contrat a été lancé en juin. Logica a défini une architecture de référence contractant et a produit un document sur les impératifs système qui doit servir de référence pour toutes les activités ultérieures. Il a été procédé à une réorientation limitée prenant en compte les résultats de la session du Conseil au niveau ministériel de Grenade.

Programme principal de réalisation (phase-C/D)

Le coup d'envoi des sous-contrats relatifs aux instruments MERIS, MIPAS et RA-2 a marqué le démarrage de la phase-1 de POEM-1. Pour l'AMI, les travaux n'ont pas été mis en route dans l'attente des résultats de la session du Conseil au niveau ministériel. De même, les activités d'analyse système chez le maître d'oeuvre mission ont été limitées à ce qui était indépendant de la configuration.

Une proposition complète de phase-C/D reçue le 12 octobre pour la configuration antérieure de POEM-1, comprenant l'AMI, est en cours d'évaluation et de négociation.

A Grenade, les ministres ont décidé d'inclure dans le programme POEM:
(i) Le satellite Envisat-1, doté du radar à synthèse d'ouverture de pointe (ASAR) au lieu de l'AMI mais dépourvu des instruments météorologiques opérationnels que l'Agence avait initialement prévu d'embarquer sur la première mission.
(ii) La mission Metop-1 de météorologie et de surveillance du climat en orbite polaire, avec participation d'Eumetsat, mettant en oeuvre les instruments ASCAT et MIMR.

Envisat-1 et Metop-1 reposeront tous deux sur la plate-forme polaire européenne.

Le maître d'oeuvre a depuis lors reçu comme nouvelles directives d'étudier la configuration d'Envisat-1 en partant des résultats d'études préparatoires menées par l'Exécutif avant la session du Conseil de Grenade.

Un appel d'offres complémentaire est en préparation pour l'approvisionnement de phase-C/D des instruments ASAR et GOMOS et d'une réplique du radiomètre hyperfréquence ERS. Il sera prochainement adressé à l'industrie.

Eureca

D'une façon générale, Eureca a fonctionné de façon satisfaisante au cours de ses quatre premiers mois en orbite. Comme il l'a été dit lors d'une réunion du Groupe de travail 'Expérimentateurs' tenue le 19 novembre 1992, environ 60% du programme d'expériences ont déjà été accomplis. Les données relatives au déroulement des expériences en science des matériaux paraissent bonnes dans l'ensemble et les chercheurs attendent leurs échantillons pour les soumettre à une analyse détaillée. Les instruments de science spatiale ont donné de bons résultats. Dans le domaine de l'astronomie des rayons X, trois nouvelles sources ont été identifiées à ce jour. Quant aux démonstrations technologiques, toutes les expériences de télécommunications interorbitales et de propulsion ionique ont été menées à bien.

Main Development Programme (Phase-C/D)
As a start up of POEM-1 Phase-1, the MERIS, MIPAS and RA-2 subcontracts have been kicked off. AMI work was not initiated awaiting the outcome of the Granada Ministerial Council. Likewise, system-analysis activities at the mission prime contractor were limited to work that was configuration-independent.

A full Phase-C/D proposal was received on 12 October for the earlier POEM-1 configuration including AMI. This is under evaluation and negotiation.

In Granada, the Ministers decided to include within the POEM Programme:
(i) Envisat-1, a satellite including the Advanced Synthetic Aperture Radar (ASAR) instead of the AMI, but without the operational meteorological instruments originally foreseen to be embarked on the first mission Agency.
(ii) Metop-1, a polar-orbiting meteorological and climate-monitoring mission with the participation of Eumetsat and including the ASCAT and MIMR instruments.

Both Envisat-1 and Metop-1 are to be based upon the European Polar Platform.

The prime contractor has since been redirected to study the Envisat-1 configuration on the basis of study results prepared by the Executive prior to the Granada Council.

A complementary Request for Proposal is in preparation to cover the Phase-C/D procurement of ASAR, GOMOS and a copy of the ERS Microwave Radiometer. This will be released to industry shortly.

Eureca

Overall, Eureca has performed satisfactorily throughout its first four months in orbit. As reported during an Investigator Working Group meeting on 19 November, about 60% of the experimental programme has already been accomplished.

Monitoring data from the material-science experiments generally looked good and the scientists are looking forward to receiving their test samples for detailed analysis. In the area of space science, the instruments performed well. In the field of X-ray astronomy, three new X-ray sources have been identified so far. As far as the technology demonstrations are concerned, the inter-orbit communication and ion-propulsion experiments have all been completed successfully.

Work in industry, at ESA and at NASA is now concentrating on the preparation of the retrieval mission for Eureca. The current planning at NASA foresees that Eureca will be retrieved on mission STS-57 by Space Shuttle 'Endeavour', due to be launched on 28 April 1993.

Space Station Freedom/Columbus

The Columbus Programme's content and schedule have remained practically unchanged since the end of August, and has been proposed in the form of four elements at the Ministerial Council Meeting in Granada (Spain) on 9/10 November 1992: the Attached Laboratory development, the Precursor Flights and the Future European Station studies reported here, and the Polar Platform activities reported separately.

The Council approved the execution of the Programme and, at the same time, gave instructions on how to reconcile the programme budget with the financial resources of the Participating States. The Council also established the objectives of negotiation with NASA in the area of operating costs, in view of complementary decisions to be taken in 1995.

Attached Laboratory
The technical baseline and launch date have been maintained since the last report; industrial activities are continuing normally to achieve the target launch date of end-1999, as agreed with NASA.

Matra Marconi Space (F) has joined DASA (D) and Alenia (I) in the Euro-Columbus Consortium charged with development of the Attached Laboratory.

Work has progressed regularly on ground-segment activities and the preparations for utilisation.

Precursor flights
The proposed elements presently include one Spacelab flight in 1997, one Eureca flight with planning still to be defined, and two Mir flights, in 1994 and 1995. The final content is being discussed in the light of the funding available and of the level of cooperation to be achieved with international partners (NASA, Japan).

Future European Station
The studies with NPO Energia that started earlier in 1992 are continuing. The programme element proposed, starting in 1993, should cover ESA's participation in the Mir-2 Station, and the conceptual study of a Euro/CIS station after 2005.

Long-term programme
The EXEMSI experiment has progressed and the three men and one woman emerged from the isolation chambers at the beginning of November, after two months in isolation. The results are now being analysed.

Dans l'industrie, à l'ESA et à la NASA, on s'attache actuellement à préparer la mission de récupération d'Eureca. D'après le calendrier actuel de la NASA, Eureca sera récupéré au cours de la mission STS-57 par la navette spatiale Endeavour dont le lancement est prévu le 28 avril 1993.

Station spatiale Freedom/Columbus

Le contenu et le calendrier du programme Columbus sont restés pratiquement inchangés depuis fin août 1992; il a été proposé à la session du Conseil réuni au niveau ministériel à Grenade les 9 et 10 novembre 1992 d'exécuter ce programme en quatre éléments: développement du laboratoire raccordé, vols précurseurs, études sur la future station européenne, dont il est question ici, et activités relatives à la plate-forme polaire. abordées dans un autre paragraphe.

Le Conseil a approuvé l'exécution de ce programme et a, dans le même temps, donné des instructions sur la façon de concilier le budget du programme et les ressources financières des Etats participants. Le Conseil a également fixé les objectifs des négociations avec la NASA sur les coûts d'exploitation, en vue des décisions complémentaires qui doivent être prises en 1995.

Laboratoire raccordé

La base de référence technique et la date de lancement ont été mainenues depuis le dernier rapport. Les activités industrielles se poursuivent normalement en vue du lancement prévu fin 1999, comme il a été convenu avec la NASA.

Matra Marconi Space a rejoint DASA et Alenia au sein du consortium Euro-Columbus chargé du développement du laboratoire raccordé.

Les travaux relatifs au secteur sol et aux activités préparatoires de l'utilisation progressent régulièrement.

Vols précurseurs

Les vols précurseurs proposés actuellement incluent un vol Spacelab en 1997, un vol Eureca dont le calendrier reste à définir et deux vols Mir, en 1994 et 1995. Leur contenu final est en cours d'examen à la lumière des fonds disponibles et du niveau de coopération visé avec les partenaires internationaux (NASA, Japon).

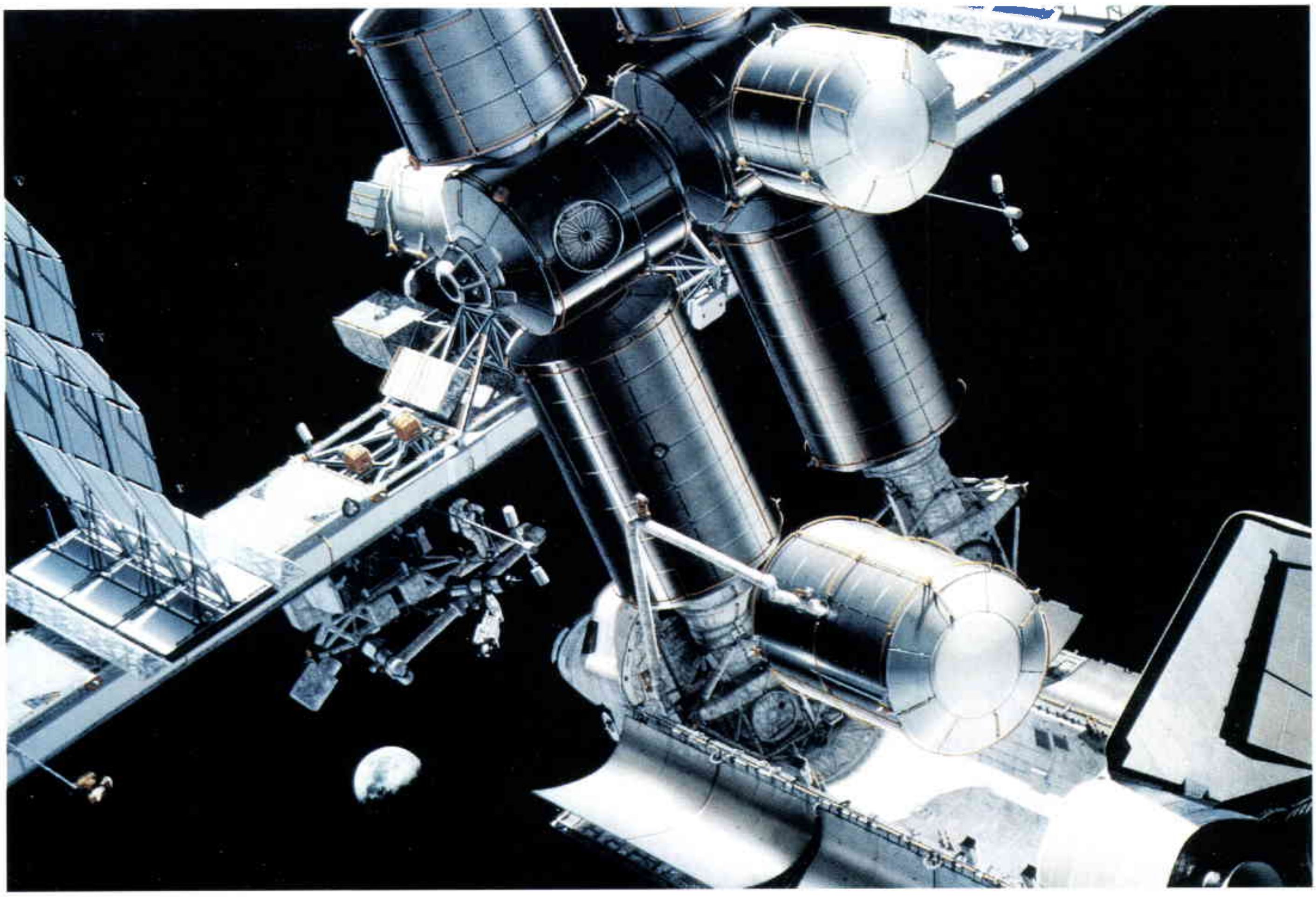
Future station européenne

Les études entamées en 1992 avec NPO Energia se poursuivent. L'élément de programme proposé, qui commence en 1993, devrait inclure la participation de l'ESA à la station Mir-2 et l'étude de la conception d'une station Euro/CEI après 2005.

Programme à long terme

L'expérience EXEMSI s'est poursuivie jusque début novembre, date à laquelle les participants, trois hommes et une femme, sont sortis de l'enceinte confinée dans laquelle ils ont été isolés pendant deux mois. Les résultats de l'étude sont à l'analyse.

Artist's impression of the Space Station



Publications

The documents listed here have been issued since the last publications announcement in the ESA Bulletin. Requests for copies should be made in accordance with the Table and using the Order Form inside the back cover of this issue.

ESA Journal

The following papers have been published in ESA Journal Vol. 16, No. 4:

THE PICO GRAVITY BOX:
AN EFFICIENT PASSIVE NOISE ATTENUATOR IN SPACE
G. CATASTINI ET AL.

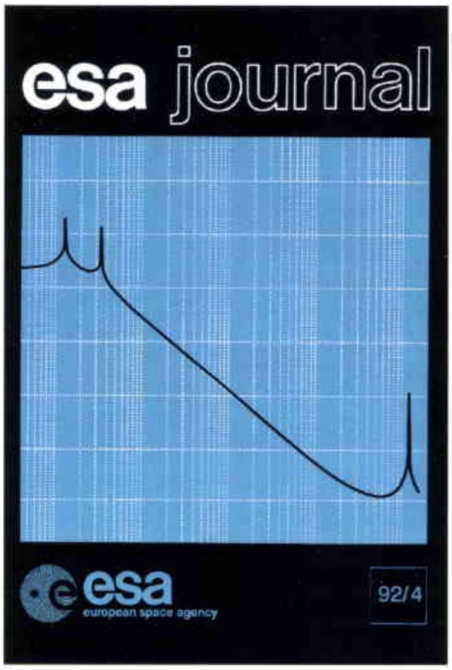
FLYING QUALITIES OF THE HERMES SPACEPLANE AND THE SHAPE DEFINITION PROCESS
E. RAILLON, P. PARNIS & N. DEVAUX

EFFECT OF PRE-STRESSING ON THE BEHAVIOUR OF CFRP UNDER GAMMA IRRADIATION
S.G. BURNAY

OPTIMUM ORBIT SELECTION FOR TWO-VEHICLE RENDEZVOUS
C.R. MCINNES

CIS COMMUNICATION FACILITIES, DATA TRANSMISSION, AND COMPUTER-AIDED EXPERIMENT EVALUATION FOR USERS OF THE MIR SPACE STATION
W. GRIETHE & J. BURFEINDT

A SPACE-PHYSICS QUERY LANGUAGE FOR THE EUROPEAN SPACE INFORMATION SYSTEM
S.N. WALKER ET AL.



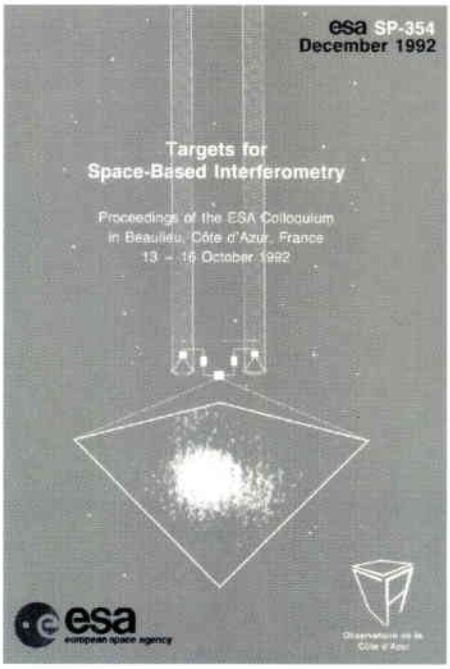
ESA Special Publications

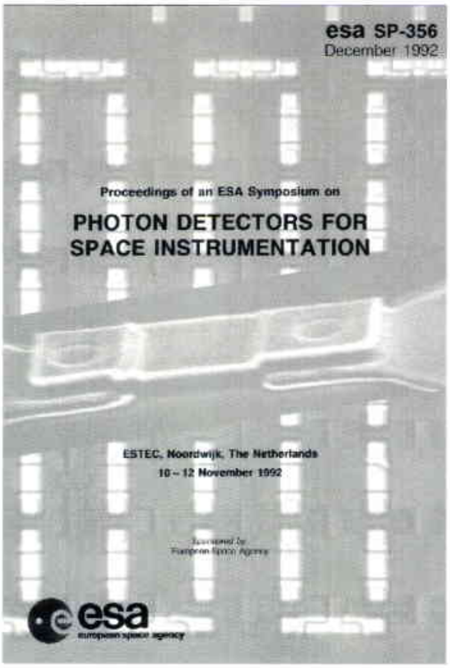
ESA SP-333 VOLS I & II // PRICE 150 DFL (TWO VOLS)
PROCEEDINGS OF THE VIIIth EUROPEAN SYMPOSIUM ON MATERIALS AND FLUID SCIENCES IN MICROGRAVITY
(ED. B. KALDEICH)

ESA SP-336 // PRICE 90 DFL
ADVANCED MATERIALS FOR LIGHTWEIGHT STRUCTURES — PROCEEDINGS OF AN INTERNATIONAL SYMPOSIUM
(ED. W.R. BURKE)

ESA SP-348 // PRICE 90 DFL
CORONAL STREAMERS, CORONAL LOOPS, AND CORONAL AND SOLAR WIND COMPOSITION — PROCEEDINGS OF THE FIRST SOHO WORKSHOP
(ED. C. MATTOK)

ESA SP-354 // PRICE 70 DFL
TARGETS FOR SPACE-BASED INTERFEROMETRY — PROCEEDINGS OF AN ESA COLLOQUIUM
(ED. C. MATTOK)





ESA SP-356 // PRICE 90 DFL
PHOTON DETECTORS FOR SPACE INSTRUMENTATION — PROCEEDINGS OF AN ESA SYMPOSIUM
(EDS. T.D. GUYENNE & J.J. HUNT)

ESA SP-1155 // 25 PRICE DFL
THE CD-ROM GUIDE TO ERS-1
(EDS. G. TREIBNIG & B. BATTRICK)

ESA Brochures

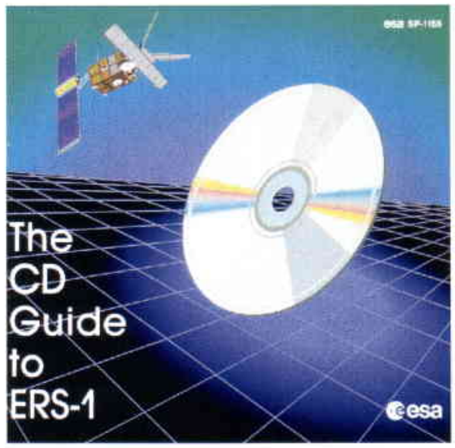
ESA HSR-3 // PRICE 25 DFL
CHOOSING ESRO'S FIRST SCIENTIFIC SATELLITES
(ED. A. RUSSO)

ESA HSR-4 // PRICE 25 DFL
THE EARLY ACTIVITIES OF COPERS AND THE DRAFTING OF THE ESRO CONVENTION (1961/62)
(ED. J. KRIGE)

ESA Newsletters

NEWS AND VIEWS, VOL. 17, NO. 3/4, NOVEMBER 1992 (NO CHARGE)
(ED. N. LONGDON)

OBSERVATION DE LA TERRE, NO. 39, OCTOBER 1992 (NO CHARGE)
(EDS. T.D. GUYENNE & N. LONGDON)



PREPARING FOR THE FUTURE, VOL. 2, NO. 4, DECEMBER 1992
(NO CHARGE)
(EDS. N. LONGDON & S. HEERD)

ESA Procedures, Standards and Specifications

ESA PSS-03-1101 ISSUE 1 REV. 1 //
NO CHARGE
COMPOSITES DESIGN HANDBOOK
ESA STRUCTURAL ENGINEERING SECTION

15th International Communications Satellite Systems Conference

San Diego, California, February 28 — March 3, 1994

(Call for papers — Abstract deadline April 14, 1993)

The 15th International Communications Satellite Systems Conference will be held in San Diego, Calif., February 28 – March 3, 1994, in participation with IEEE Communications Society, Canadian Aeronautic and Space Institute, Deutsche Gesellschaft für Luft- und Raumfahrt, Institute of Electronics, Information and Communication Engineers of Japan and Association Aeronautique et Astronautique de France.

Topics to be addressed at the conference include all kinds of satellite communications systems and networks – international, regional and domestic; civilian and military; government and commercial and fixed, broadcast and mobile service. Sessions will be organized around themes of system designs, analysis, architectures, operations (both launch and on-orbit), and hardware technologies. Morning and afternoon technical sessions will consist of oral presentations (with visual aids) of papers accepted for the conference proceedings. A tutorial colloquium will be held on Sunday, February 27, 1994.

Abstracts should be 500 – 1000 words in length in English and should be prepared in accordance with the Abstract Submittal form *(available from AIAA Headquarters, 370 L'Enfant Promenade, SW, 10th Floor, Washington, DC 20024-2518, Tel (202) 646-7463, Fax (202) 646-7508)*. The first page must contain the conference name, title of paper, authors' names including affiliations, complete mailing address and telephone and FAX numbers. Please indicate one author to receive all correspondence. Sponsor and/or employer approval of each paper is the responsibility of each author. Failure to obtain the necessary approvals can result in last minute withdrawal of the paper. Abstracts should be submitted in triplicate to the technical program chairperson at the address that follows by April 14, 1993.

Abstracts are solicited on the following and related topics:

- International systems
- Regional and national systems
- Mobile systems (GEO, LEO and MEO)
- Military systems
- Mobile systems (maritime, aero and land)
- Advanced system concepts
- Direct broadcast – TV and audio
- Satellite link signal processing
- Transmission processing – TDMA, FDMA, DAMA, etc.
- Modulation and coding
- Communications payloads
- Onboard processing and switching
- Advanced technology development
- Spacecraft and payload electronics
- Terrestrial network interfaces
- Frequency and orbit utilization
- Satellite antennas (multibeam et al)
- SDN, SONET and gigabit rate satellite links
- Component advances and developments
- Ground stations and antennas
- Orbits (GEO, LEO, elliptical, inclined)
- Launchers
- Satellite communications system economics
- Operational experience

Notification of acceptance or rejection will be mailed to authors by June 7, 1993, from the technical chair. The full-length paper will be due by August 6, 1993, for technical peer review. Photoready manuscripts, as prescribed by AIAA editorial instructions, are due at AIAA headquarters by December 10, 1993. All papers received on time will be published in a bound proceedings that will be available at the conference.

Conference General Chairperson
Mr. Raul D. Roy
TRW Space and Electronics Group
One Space Park Drive, R10/2753
Radondo Beach, CA 91078
310/812-1690 - 310/812-7110 FAX

Technical Program Chairperson
Dr. David R. McElroy
MIT Lincoln Laboratory
RM B233/244 Wood Street
Lexington, MA 02173-9108
617/981-7643 - 617/981-0785 FAX

Publications Available from ESA Publications Division

Publication	Number of issues per year	Scope/Contents	Availability	Source
Periodicals				
ESA Bulletin	4	ESA's prime magazine	Free of charge	ESA Publications Division, ESTEC, 2200 AG Noordwijk, The Netherlands
ESA Journal	4	ESA's learned journal	,,	
Earth Observation Quarterly (English or French)	4	Remote-sensing newspaper	,,	,,
ECSL News	4	Newspaper of the European Centre for Space Law (under the auspices of ESA)	,,	,,
Reaching for the Skies	4	Space Transportation Systems newspaper	,,	,,
Columbus Logbook	4	Space Station/Columbus newspaper	,,	,,
Microgravity News (English with French summaries)	3	Microgravity Programme newspaper	,,	,,
Preparing for the Future	4	Technology Programme newspaper	,,	,,
News & Views	4	ESA Information Retrieval Service's newspaper	,,	ESRIN, Via Galileo Galilei, CP64, 00044 Frascati, Italy
Monographs	**Code**			
Conference Proceedings	(SP-xxx)	Volumes of specific Conference papers	Prices below	ESA Publications Division, ESTEC, 2200 AG Noordwijk, The Netherlands
Scientific/Technical Monographs	(SP-xxxx)	Specific/detailed information on graduate-level subjects	,,	
ESA Brochures	(BR-xxx)	Summaries of less than 50 pages on a specific subject	,,	,,
ESA Folders	(F-xxx)	'Folders' giving short descriptions of subjects for the space-interested layman	Free of charge	,,
Scientific & Technical Reports	(STR-xxx)	Graduate level — reflecting ESA's position on a given subject	Prices below	,,
Scientific & Technical Memoranda	(STM-xxx)	Graduate level — latest but not finalised thinking on a given subject	,,	,,
Procedures, Standards & Specifications	(PSS-xxx)	Definitive requirements in support of contracts	,,	,,
Other Publications				
Training Manuals	(TM-xxx)	Series for education of users or potential users of ESA programmes, services or facilities	,,	,,
Technical Translations	(TT-xxx)	Translations of national space-related documents — (Microfiche or photocopy only)	Prices from ESRIN	ESRIN, Via Galileo Galilei, CP64, 00044 Frascati, Italy, or ESA/IRS Office, 8-10 Mario Nikis 75738 Paris 15, France
Public-relations material		General literature, posters photographs, films, etc.		ESA Public Relations Service 8-10 rue Mario-Nikis 75738 Paris 15, France

Charges for printed documents	E0	E1	E2	E3	E4
Number of pages in document:	1—50	51—100	101—200	201—400	401—600
Price (Dutch Guilders)	25	35	50	70	90

Order Form for ESA Publications

IMPORTANT

1. Orders must be accompanied by a Cheque or International Banker's Draft, in Dutch Guilders, made payable to 'ESA Publications Division'. No publications will be sent before receipt of payment. The minimum value order accepted from 1 January 1991 is Dfl 75. (Does not apply to periodicals or folders, which are free of charge).
2. Mailing free-of-charge (sea mail outside Europe). If airmail is required outside Europe, please add 10% to total.

RETURN TO: FINANCE DIVISION (EFA/P)
ESTEC, POSTBUS 299
2200 AG NOORDWIJK
THE NETHERLANDS

No. of copies	ESA reference	Title	Price per copy, Dfl.	Total Dfl.

Airmail (outside Europe)[2] ☐ yes — If yes, add 10% of total: ....

MINIMUM ORDER Dfl. 75. — Total amount enclosed: Dfl. ....

MAILING ADDRESS (Print carefully)

Name ....

Function ....

Organisation ....

Mailing Address ....

....

Town & Postal Code ....

Country ....

Date .... Signature ....

METHOD OF PAYMENT (Please tick box)

☐ Cheque
☐ International Banker's Draft

enclosed, made payable to ESA Publications Division.

esa
european space agency
agence spatiale européenne

Member States

Austria
Belgium
Denmark
France
Germany
Ireland
Italy
Netherlands
Norway
Spain
Sweden
Switzerland
United Kingdom

Etats membres

Allemagne
Autriche
Belgique
Danemark
Espagne
France
Irlande
Italie
Norvège
Pays-Bas
Royaume-Uni
Suède
Suisse

European Space Agency / Agence Spatiale Européenne
8 - 10 rue Mario-Nikis, 75738 Paris Cedex 15, France