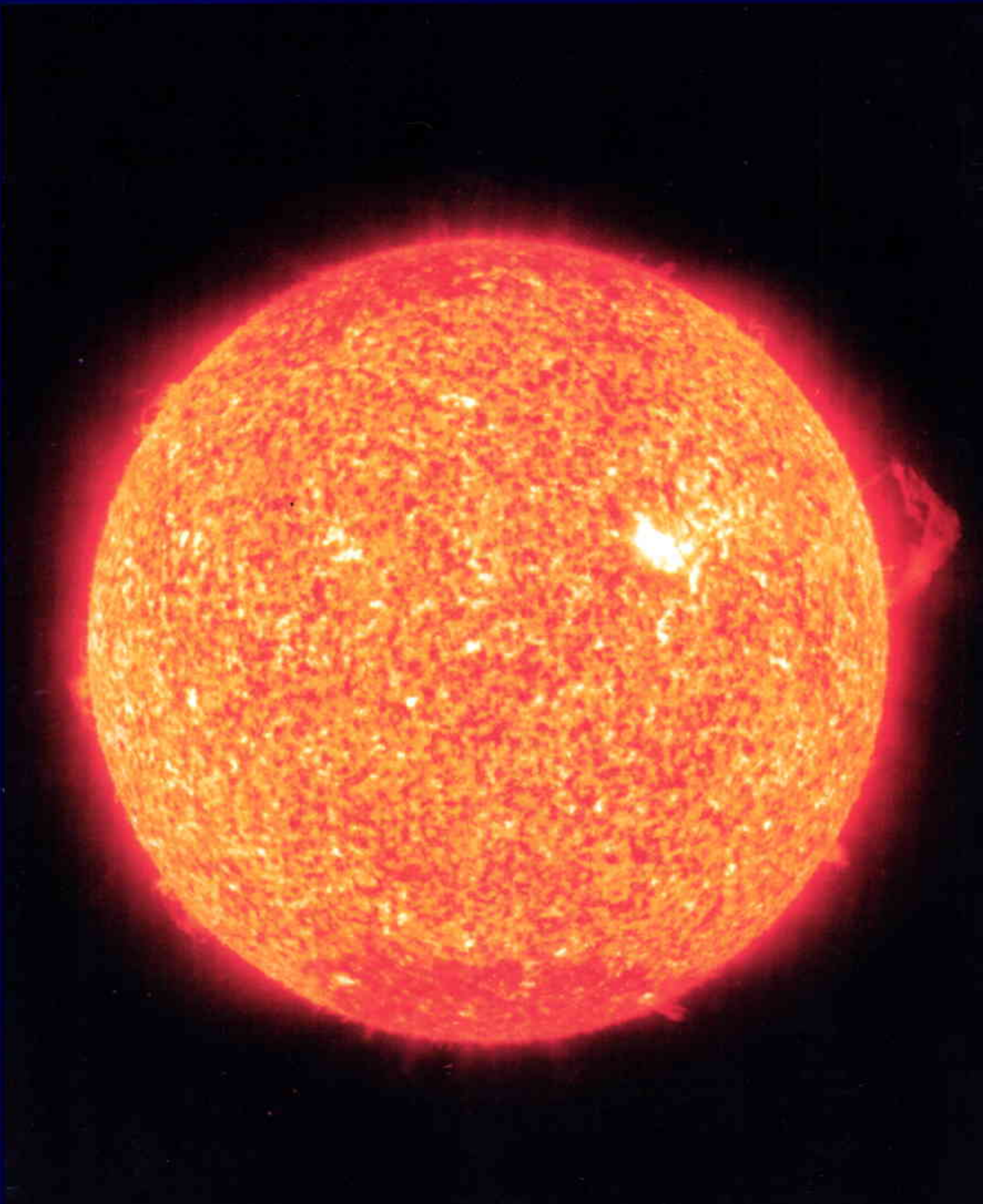
esa bulletin

number 86 - may 1996



European Space Agency
Agence spatiale européenne

european space agency

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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 Finlande, la France, l'Irlande, l'Italie, la Norvège, les Pays-Bas, le Royaume-Uni, la Suède et la Suisse. Le Canada bénéficie d'un statut d'Etat coopérant.

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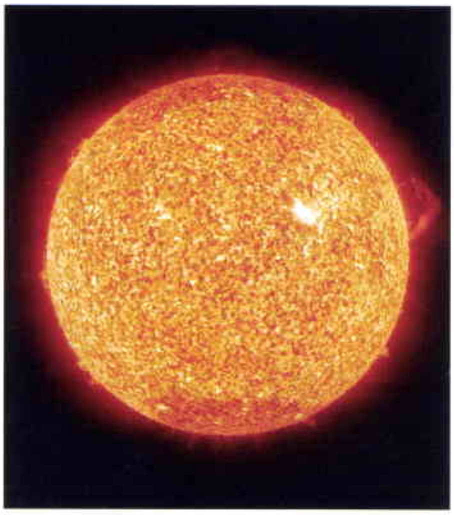

Cover: The violence of the Sun, unmasked by SOHO's Extreme Ultraviolet Imaging Telescope (EIT)

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Printed in The Netherlands ISSN 0376-4265

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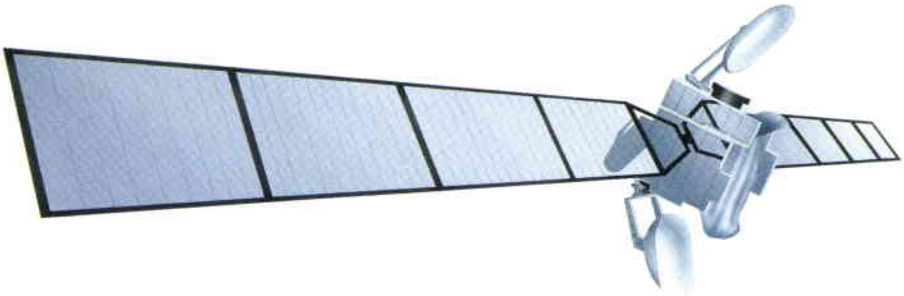

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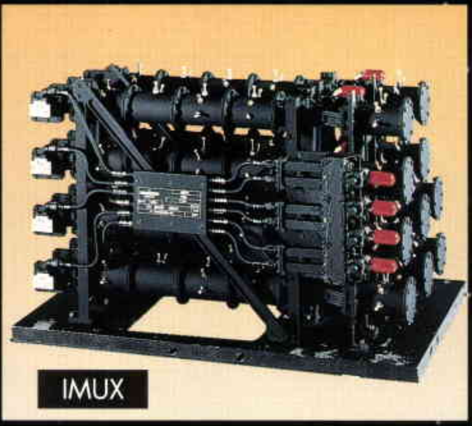
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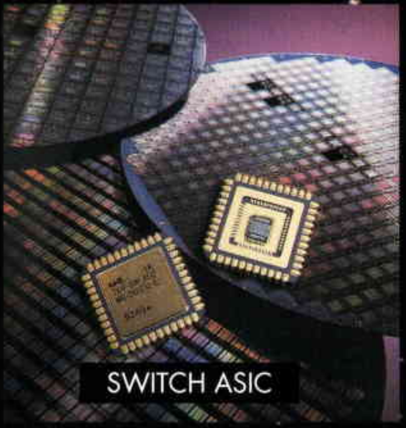
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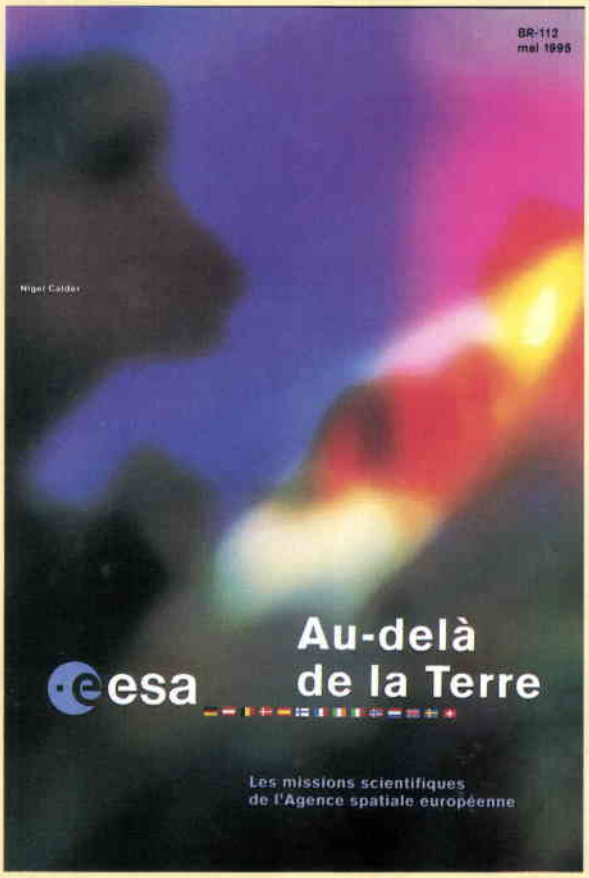

Au-delà de la Terre

Les missions scientifiques de l'Agence spatiale européenne (ESA)

de Nigel Calder

'Au-delà de notre ciel teinté de bleu par l'atmosphère terrestre s'étend l'Univers, ce vide spatial noir ponctué de planètes, d'étoiles et de galaxies. C'est le royaume des chercheurs spatiaux.'

Nigel Calder, écrivain très connu en Grande-Bretagne pour la qualité de ses écrits scientifiques, brosse ici un tableau complet et vivant du programme de recherche spatiale de l'ESA, en nous donnant un avant-goût des projets que l'Agence compte mettre en oeuvre au XXI^{e} siècle.

La vigueur et la diversité de cette recherche s'imposent au lecteur. *Au-delà de la Terre* présente douze missions différentes, en mettant l'accent sur les raisons humaines et scientifiques qui sous-tendent l'immense travail à la clé de la recherche spatiale. La description proprement dite des missions est accompagnée de détails techniques apparaissant sous forme de tableaux et d'illustrations.

Cet ouvrage traite principalement du programme scientifique actuel de l'Agence : Horizon 2000. Les quatre grandes missions dites pierres angulaires — Soho et Cluster, XMM, Rosetta, First — ainsi que les différentes missions de taille moyenne y sont exposées. La première partie du document porte sur les engins spatiaux chargés d'explorer les environs de la Terre, le Soleil et d'autres destinations du système solaire, la deuxième étant consacrée aux télescopes d'astronomie sur orbite terrestre. Dans l'un et l'autre cas, l'auteur donne un aperçu du contexte historique et international dans lequel s'inscrivent les missions.

La troisième partie du document projette le lecteur dans la deuxième décennie du XXI^{e} siècle et traite plus particulièrement des trois grandes missions du programme Horizon 2000 Plus de l'ESA, qui couvre la période 2006-2016. Explorer la mystérieuse planète Mercure, exploiter les avantages de l'interférométrie pour atteindre un degré de précision inégalé dans le domaine de l'observation astronomique, partir à la recherche des ondes gravitationnelles — tels sont les trois projets majeurs de l'Agence pour cette période, conciliant les nécessités de la planification à long terme et le caractère imprévisible de la recherche.

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The First Results from ISO

M.F. Kessler
ISO Science Operations, ESA Space Science Department, Villafranca, Spain

This article gives a summary of the early in-orbit performance of the Agency's recently launched Infrared Space Observatory (ISO) spacecraft and its instruments and presents some of the initial scientific results.

Chronology of ISO Events

17 Nov. 1995 — Launch from Kourou at 02.20 CET
19 Nov. 1995 — Perigee-raising manoeuvre (from 500 to 1000 km)
21 Nov. 1995 — Start of 'Satellite Commissioning Phase'
24 Nov. 1995 — Apogee-lowering manoeuvre – operational orbit attained
27 Nov. 1995 — Ejection of 'cryo-cover'
28 Nov. 1995 — First light with ISOCAM – M 51
29 Nov. 1995 — First light with ISOPHOT – Gamma Draconis
30 Nov. 1995 — First light with LWS – S 106
01 Dec. 1995 — First light with SWS – Gamma Draconis
08 Dec. 1995 — End of 'Satellite Commissioning Phase'
09 Dec. 1995 — Start of 'Performance Verification Phase'
03 Feb. 1996 — End of 'Performance Verification Phase'
04 Feb. 1996 — Start of 'Routine Operations'

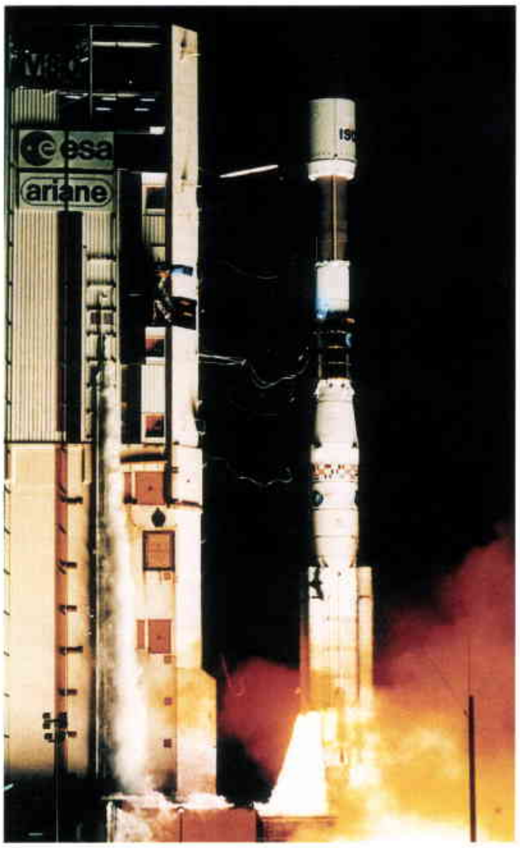


Figure 1. Lift-off of the Ariane-44P carrying ISO into orbit

Introduction

The Agency's Infrared Space Observatory (ISO) was given a perfect launch by an Ariane-44P vehicle (Fig. 1) into its planned elliptical transfer orbit, with lift-off from Kourou occurring at 02.20 CET on 17 November 1996.

The first 21 days after launch were devoted to the so-called 'Satellite Commissioning Phase'. During this period, the operational orbit was attained, the cover that had closed off the cryostat on the ground was ejected, the spacecraft was shown to be in excellent condition, 'first light' for all instruments was achieved, engineering checks were successfully completed on all four scientific instruments, and the integrated ground segment was validated.

The next 56 days (i.e. from 8 December to 3 February) were devoted to the so-called 'Performance Verification Phase', during which a detailed assessment of the in-flight performance of the scientific instruments was made, their core calibrations established, and planned operating modes validated. The data acquired during this period are being used to verify the pipeline data processing and its products.

Table 1 summarises the main features of the ISO instruments. A set of five articles in ESA Bulletin No. 84 (November 1995) gave a complete overview of the ISO programme.

In-orbit performance

Ariane injected ISO into a transfer orbit with a perigee of 500 km and an apogee of 71 600 km. The operational orbit (perigee of 1000 km and apogee 70 600 km) was achieved, as planned, with three uses of the hydrazine reaction-control system, on 18 November (test burn and rehearsal), on 19 November (perigee-raising manoeuvre) and on 24 November (apogee-lowering manoeuvre). An estimated 50 kg of hydrazine remains on-board, whereas only about 12 kg are needed for the planned ISO operations.

Second only to the launch in terms of tension was the release of the cryo-cover on 27 November. This cover closed the cryostat on the ground and had to be ejected before ISO could begin its in-orbit mission. As the planned eject time approached, most of the staff at the Operations Centre in Villafranca were clustered around monitors showing the gyroscope outputs. There was a huge sigh of relief when these showed the recoil of the satellite as the cover was released. Shortly thereafter, the temperatures of the cryogenic system indicated that ISO was indeed viewing cold space, and about 30 minutes later the first star was found. ISO was in business!

The Satellite Commissioning Phase showed that the spacecraft status is excellent, with all subsystems performing above specifications. The cool-down of the satellite to reach its in-orbit equilibrium temperatures was well in line with the thermal model. The cryogenic system is providing the expected temperatures and the estimated mass flow rate of the boiled-off helium seems close to predictions. Current estimates are that ISO's in-orbit lifetime will be 24 $\pm$2 months, compared with the design requirement of 18 months.

As far as the optical performance of ISO is concerned, images of point sources have been made with ISOCAM clearly showing the first Airy diffraction ring and, in some cases, the second ring is also visible. Analysis of the data has shown that the ISO telescope is diffraction-limited at a wavelength of 15 microns. Measurements at shorter wavelengths have been made and the analysis is underway.

All nominal modes of the Attitude and Orbit Control System were successfully verified. The pointing performance is also substantially better than specification, as shown in Table 2.

The Performance Verification Phase showed that the performance of the instruments is also very good. All instruments are functioning very well and as expected from the ground-based tests. Particularly satisfying is the fact that all the cryo-mechanisms are fully operational – an initial anomaly with the scanning mechanism of one of the Fabry-Perot units on the Long Wavelength Spectrometer(LWS) has been successfully resolved.

The sensitivity of the instruments is affected to varying degrees by 'glitches', caused by high-energy cosmic-ray particles impacting on the infrared detectors. These glitches result primarily in increased noise, but in some cases have necessitated modifications to instrument settings and recommendations for changes in observing strategy. ISOCAM's sensitivity is very close to pre-launch expectations. ISOPHOT, SWS and LWS are more affected and their sensitivities are less than originally predicted. The operating conditions of the detectors and the data-processing algorithms are being optimised to maximise the instruments' performance. All instruments are returning scientific data of excellent quality, and some examples of astronomical results are given in the next section.

By the end of the Performance Verification Phase, 80% of the foreseen operating modes of the instruments had been commissioned and released for use by Guest Observers.

Prior to launch, it was estimated that ISO's instruments could be operated for about 16 hours per day, this being the period when ISO is outside the van Allen belts of trapped protons and electrons. However, post-launch data show that it is possible to operate the instruments for longer periods each day. Currently, the 'science window' has a duration of 16 h 43 min; a further extension for at least some of the instruments might be possible, although sufficient data has not yet been gathered and analysed.

Table 1. Main features of ISO's scientific instruments

Instrument (Principal Investigator)	Main function	Wavelength (μm)
ISOCAM (C. Cesarsky, CEN-Saclay, F)	Camera and polarimetry	2.5 — 17
ISOPHOT (D. Lemke, MPI für Astronomie, Heidelberg, D)	Imaging photo-polarimeter	2.5 — 240
SWS (Th. de Graauw, Lab for Space Research, Groningen, NL)	Short-wavelength spectrometer	2.4 — 45
LWS (P. Clegg, Queen Mary & West Field College, London)	Long-wavelength spectrometer	43 — 198

Table 2. ISO's pointing performance

		Units	Spec.	Now
Relative Pointing Error (short-term jitter)	2 sigma, half cone, over 30 seconds	arcsec	< 2.7	0.5
Absolute Pointing Drift	2 sigma, half-cone	arcsec/h	< 2.8	< 0.1
Absolute Pointing Error (blind pointing)	2 sigma, half-cone	arcsec	< 11.7	4 – 5

Routine operations started on 4 February as planned. Observers are currently tuning up their astronomical programmes to reflect the in-orbit performance of the satellite. ISO is now making an average of 50 observations per day for the worldwide astronomical community, and shipment of these data on CD-ROMs to observers has already started.

Initial scientific results

With new instruments, offering unprecedented combinations of wavelength coverage, sensitivity, and spatial and spectral resolutions in the infrared spectral region, ISO has been looking at familiar objects in unfamiliar ways. A few of these measurements are presented here.

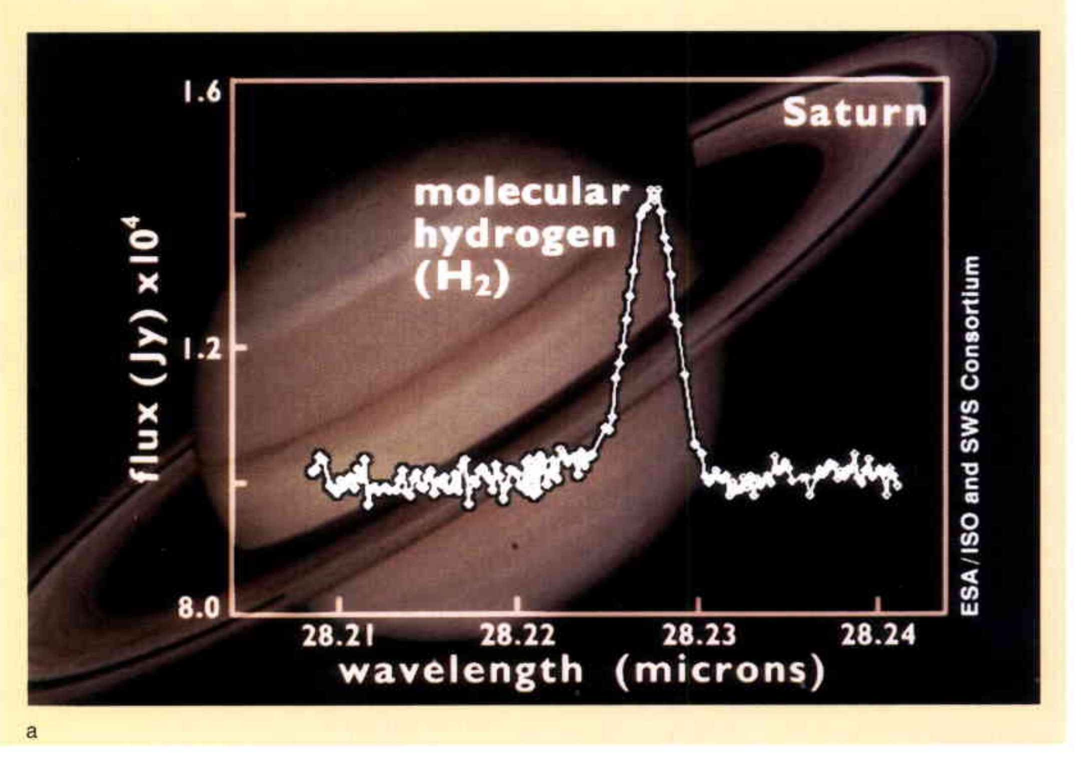
Starting close to home, ISO's spectrometers have been turning their gaze on the giant planet Saturn (Fig. 2). A variety of molecules have been detected. Deuterated molecular hydrogen (HD) will give clues to the early history of Saturn, while the measurements of molecular hydrogen, phosphine and ammonia will permit deductions about the distribution of such materials at different depths in the atmosphere, and about the 'weather' and cloud formations on Saturn.

Staying with molecules and the spectrometers, the SWS observed a cloud called GL 2591 (Fig. 3). This cloud is wrapped around a newly-forming, massive star and hides the latter from telescopes viewing at visible wavelengths. The SWS spectrum shows features due to water ice and to carbon-dioxide ice, including the first detection of the 4 micron CO_2 absorption band.

At the other end of the stellar-evolution range, the LWS has observed a young planetary nebulae, NGC 7027. This is a cloud of dust and gas, which has been ejected by a star nearing the end of its life. It illustrates the process by which the nuclear reactions in stars process hydrogen to heavier elements, which are then returned to the interstellar gas at the end of a star's life to take part in the next generation of star (and planet) formation. The great surprise with this observation was the discovery of water vapour (Fig. 4); this object is carbon-rich and the oxygen was thought to be tied up in carbon monoxide (CO) rather than in water. Detections of these commonplace molecules – water and carbon dioxide – are extremely difficult from the ground due to interference from the Earth's atmosphere. However, knowledge of their abundances is crucial to an understanding of the chemistry in space.

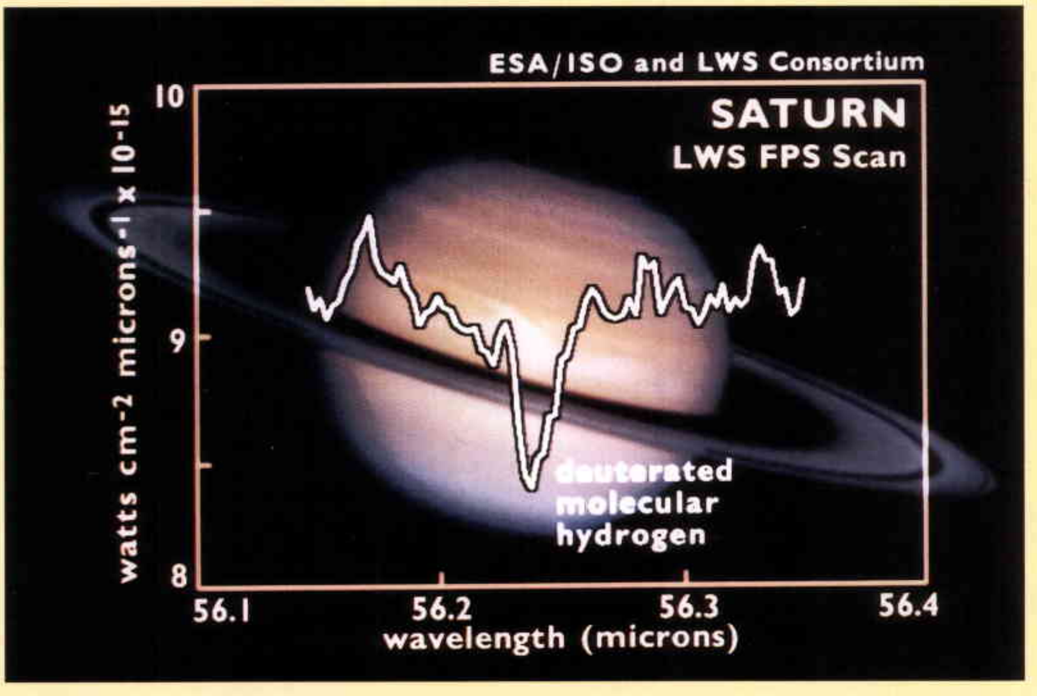
Massive stars end their lives in a supernova explosion, hurling processed matter enriched with heavy elements back into the interstellar medium. As the debris continues to expand outwards, it interacts with pre-existing clouds in interstellar space and radiates at infrared wavelengths. ISOPHOT has made a map of the supernova remnant MSH 11-54 (Fig. 5), which shows both striking similarities and differences with X-ray maps of the same object.

Figure 2. SWS and LWS instrument spectra of Saturn, overlaid on Hubble Space Telescope (HST) and Voyager visible images: (a) Molecular hydrogen (H_2) (b) Deuterated molecular hydrogen (HD) (c) Ammonia (NH_3) and phosphine (PH_3)



The LWS has been observing a 'cosmic refrigerator' at work. Clouds of gas in space radiate strongly at a wavelength of 158 microns, coming from singly ionised ions of carbon, C II. This line has been detected before, but ISO sees it easily in all kinds of places (Fig. 6), in a cloud heated by bright stars, around a dying star, in colliding galaxies and, most interestingly, in a cloud of dust and gas (infrared cirrus) so cold that it can only be seen at infrared wavelengths. The total energy released in this C II line, and lost to the object, is enormous – up to 1 per mil of the total energy radiated by our Galaxy – and thus has a real cooling effect on the interstellar gas and dust from which stars are born. Measurements such as these are essential to understanding the energy balance in astronomical objects.

Turning to external galaxies, the SWS made the first detection of the 17 micron line of molecular hydrogen in NGC 6946 (Fig. 7) and other external galaxies, thereby opening a new way of tracking the distribution of the molecular form of the most abundant element in the Universe. ISOPHOT has made a map at a wavelength of 60 microns of the same



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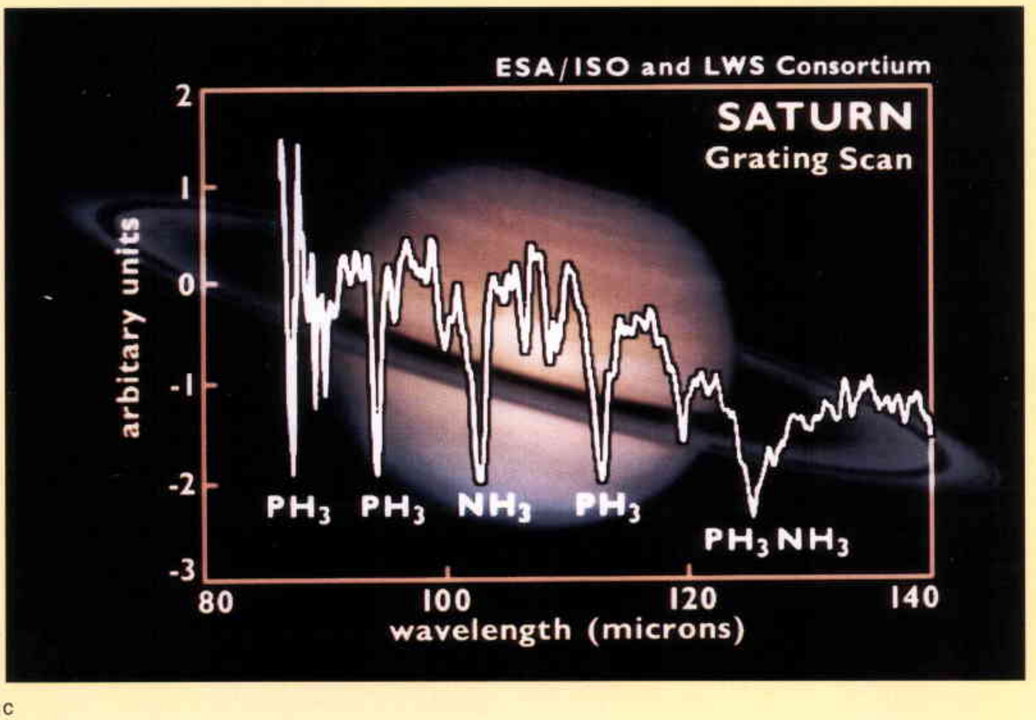

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galaxy (Fig. 8) showing an intense hot spot at its centre caused by the rapid formation of very hot stars.

Moving fully to the topic of star formation, ISOCAM has made a series of spectacular infrared images of the M 51, also known as the 'Whirlpool Galaxy' (Fig. 9). Bright spots in the spiral arms correspond with warm dust clouds where star formation is proceeding on a large scale. These are linked by regions of cooler dust along the spiral arms and in the spaces between the arms where previous generations of stars have left their debris. In the infrared, the spiral arms can be traced right into the heart of the galaxy, where there are hot spots of star formation on either side of a bright central nucleus. A companion galaxy (top in figure) looks smaller than it does by visible light because star-making is concentrated near its nucleus.

ISO's instruments have also looked at a pair of colliding galaxies, known as 'The Antennae', due to their characteristic shape at visible wavelengths or – more formally – as NGC 4038/9 or Arp 244. ISOPHOT has taken a series of measurements to determine the

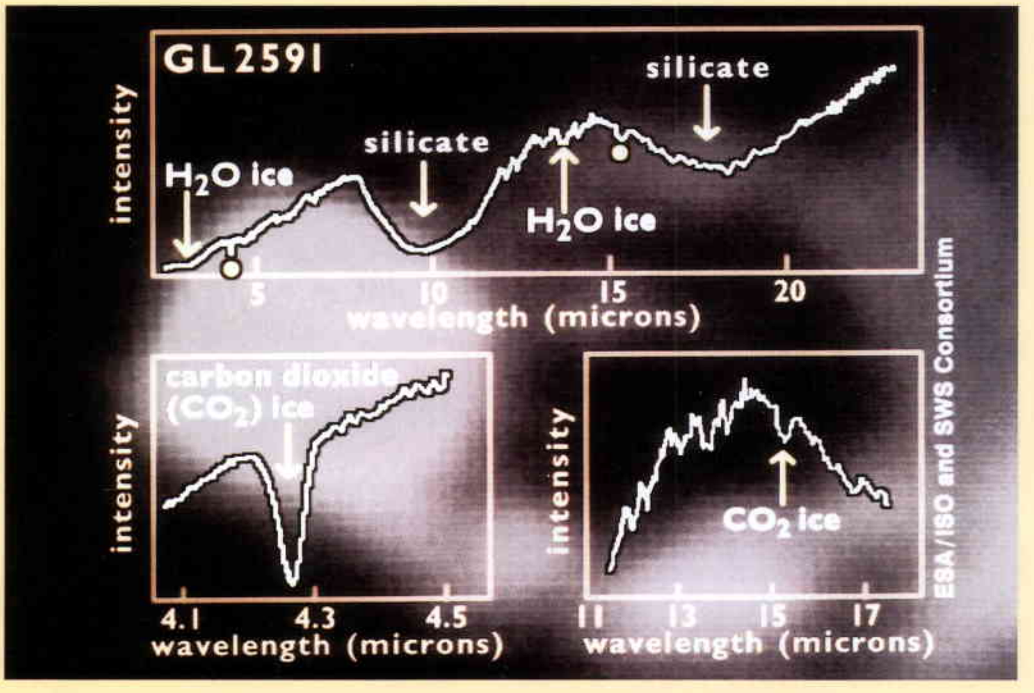

Figure 3. SWS spectra of GL 2591, overlaid on a ground-based infrared image

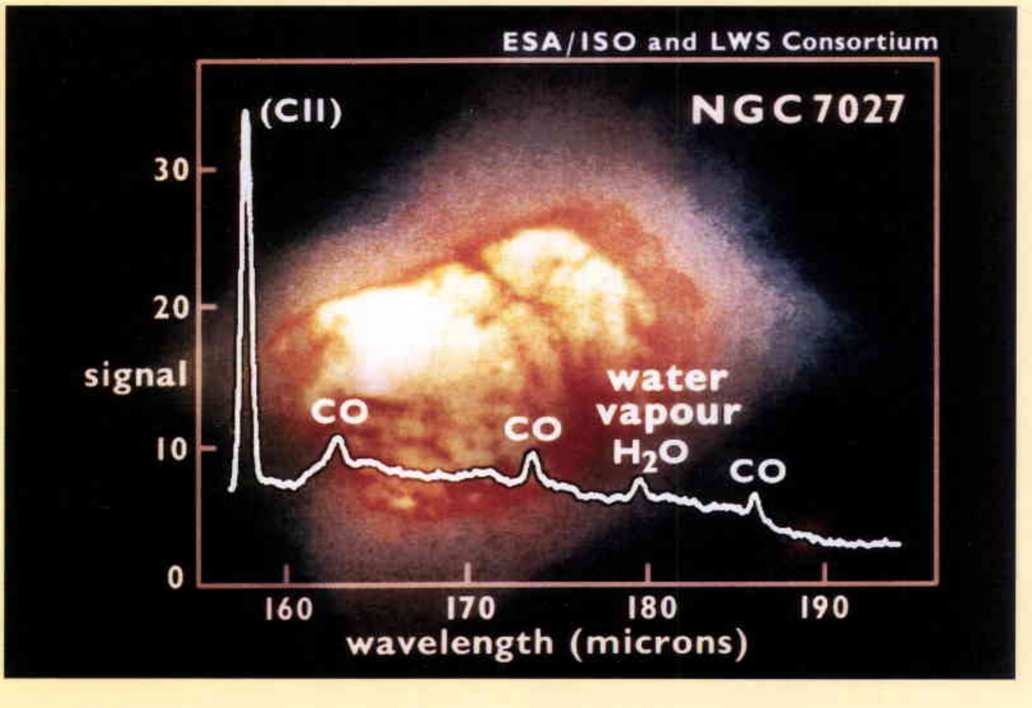

Figure 4. LWS spectrum of the planetary nebula NGC 7027, overlaid on an HST visible image

spectral shape of the energy distribution (Fig. 10). Such measurements demonstrate the width of the ISO spectral coverage and can be used, inter alia, to determine rates of star formation. ISOCAM has taken images at various wavelengths (Fig. 11) to localise the regions of star formation. Clouds of dust and gas in the two galaxies have crashed together and provoked bursts of star formation. In the lower galaxy (NGC 4039), an extended bright region, with a hot spot to the right, marks the overlap of the disks and the position of intense star formation. In the upper galaxy, the star-making is concentrated around the central nucleus. ISOCAM has also taken spectra of these objects (Fig. 12) to add another dimension to the investigation of events 60 million light years away.

Conclusion

During its early months in orbit, ISO mainly looked at known objects to establish the performance of its instruments. Even so, there have been some pleasant scientific surprises. A vast quantity of high-quality scientific data has been returned and this is increasing steadily as ISO carries out an average of 50 observations per day.

Figure 5. ISOPHOT image at a wavelength of 60 microns of the supernova remnant MSH 11-54

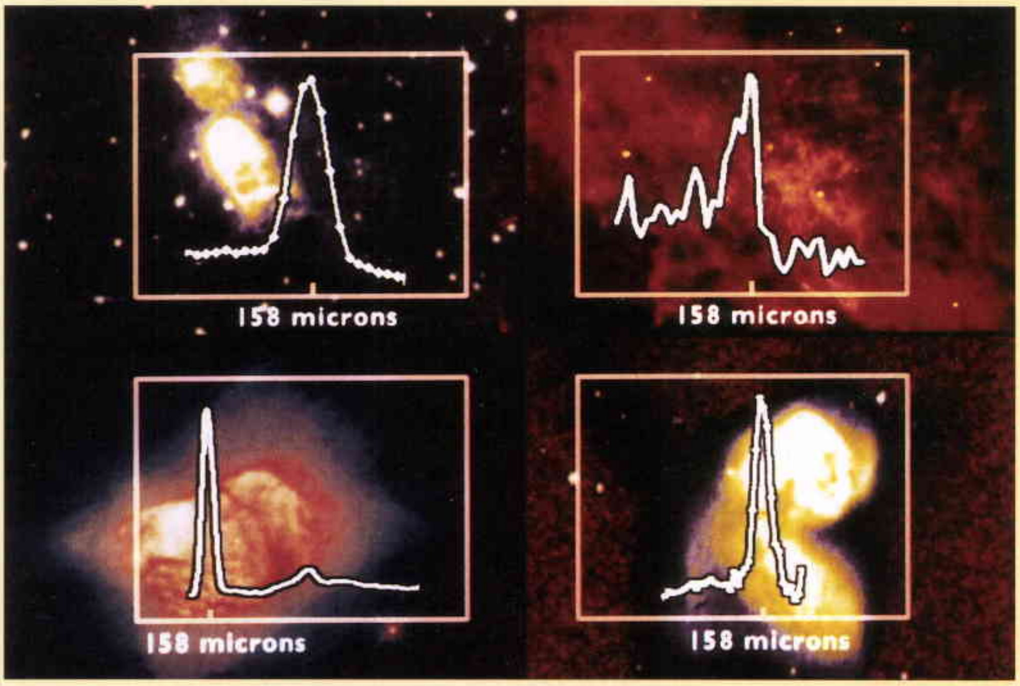

Figure 6. The C II cooling line as seen by the LWS instrument:

Top left: S 106, an H II region, consisting of ionised gas and dust

Bottom left: NGC 7027, a planetary nebula, a cloud of dust and gas ejected from a dying star

Top right: Infrared Cirrus, cold wispy dust and gas

Bottom right: the Antennae, two colliding galaxies

These few glimpses of early results from ISO are sound testimony to its potential and discovery-making power, and it is now clear that the Observatory will meet the high scientific expectations placed on it by the worldwide scientific community.

Acknowledgements

The ISO success would not have been possible without the dedication, professionalism and inspiration of countless individuals over a period stretching back nearly twenty years. Overall management was carried out by the ESA Project Team, located at ESTEC. The satellite was built by an industrial consortium, led by Aerospatiale (F) as prime contractor, and including 35 companies at its peak. Each instrument was built by a consortium of institutes and industries, led by a Principal Investigator Catherine Cesarsky (CEA, Saclay, F) for ISOCAM, Peter Clegg (QMW, London, UK) for the Long-Wavelength Spectrometer, Thijs de Graauw, (SRON, Groningen, NL) for the Short-Wavelength Spectrometer, and Dietrich Lemke (MPIA, Heidelberg, D) for ISOPHOT. A

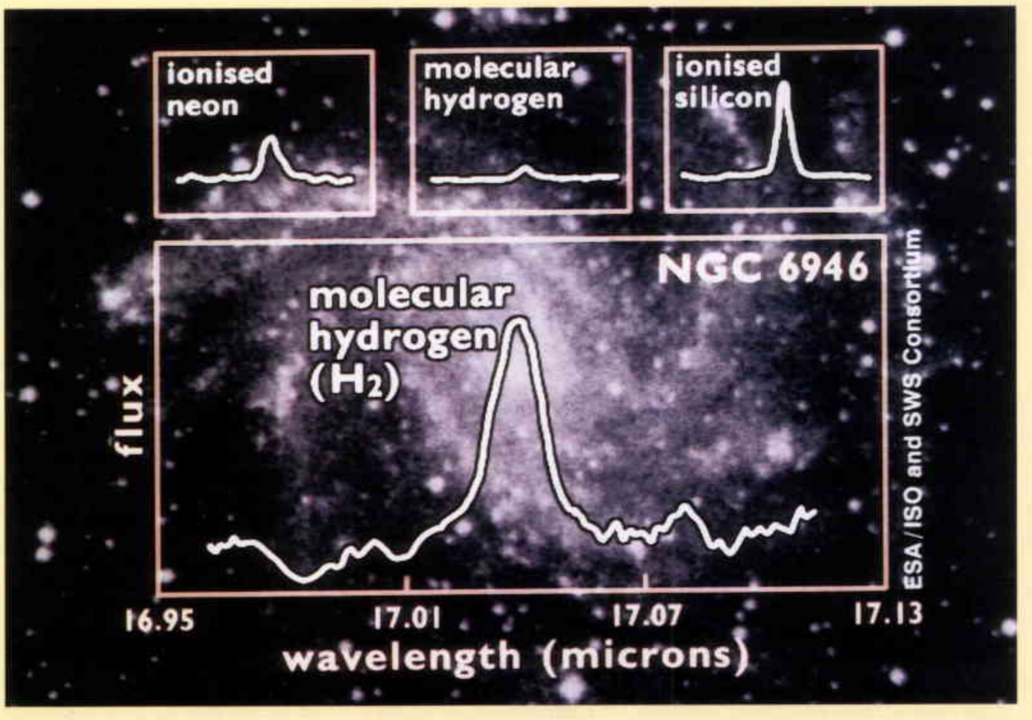

Figure 7. SWS spectrum of NGC 6946, showing molecular hydrogen emission overlaid on a visible image of the galaxy

Figure 8. ISOPHOT map of the galaxy NGC 6946 at a wavelength of 60 microns

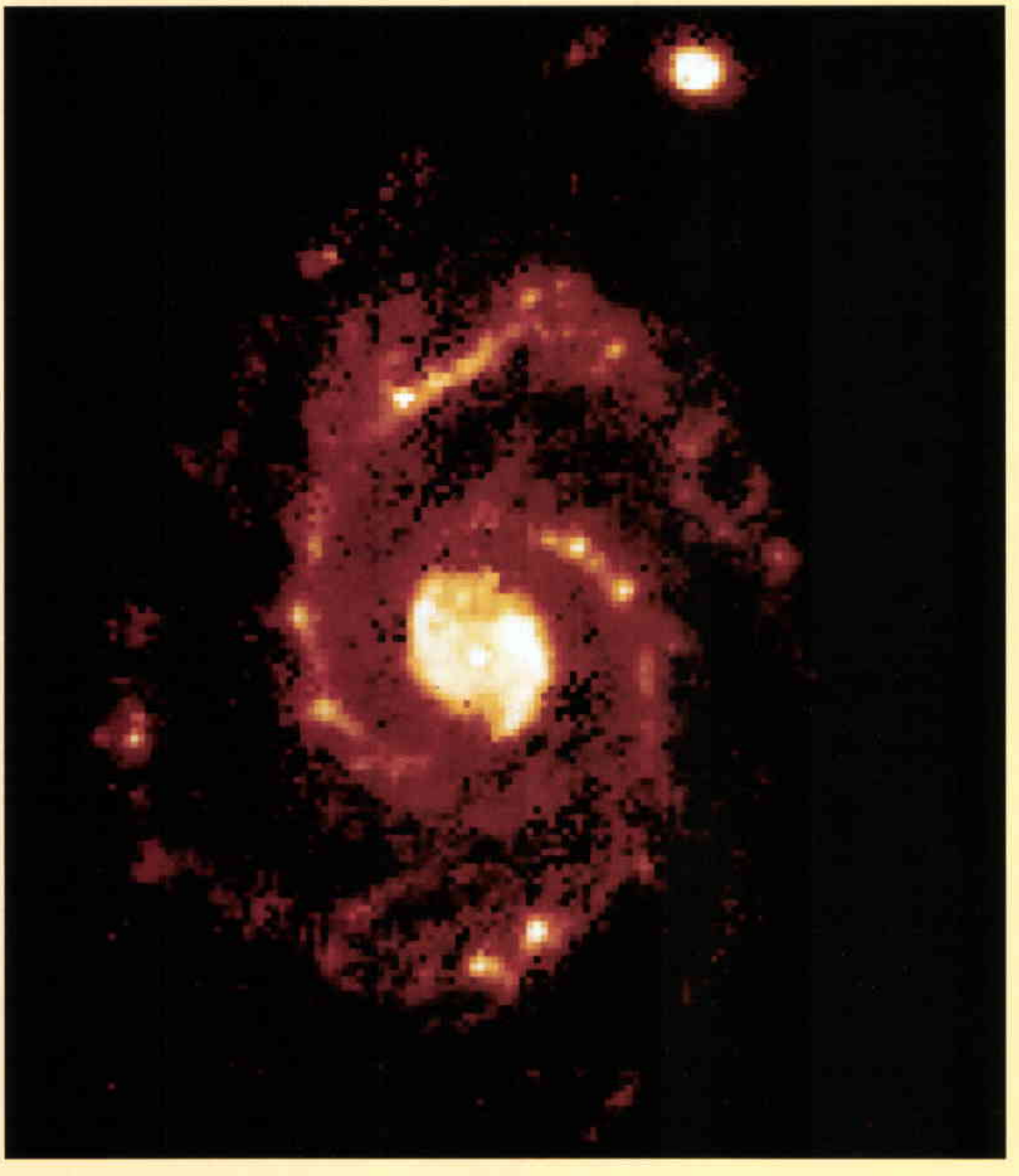

Figure 9. ISOCAM map of the Whirlpool Galaxy (M 51) at a wavelength of 15 microns

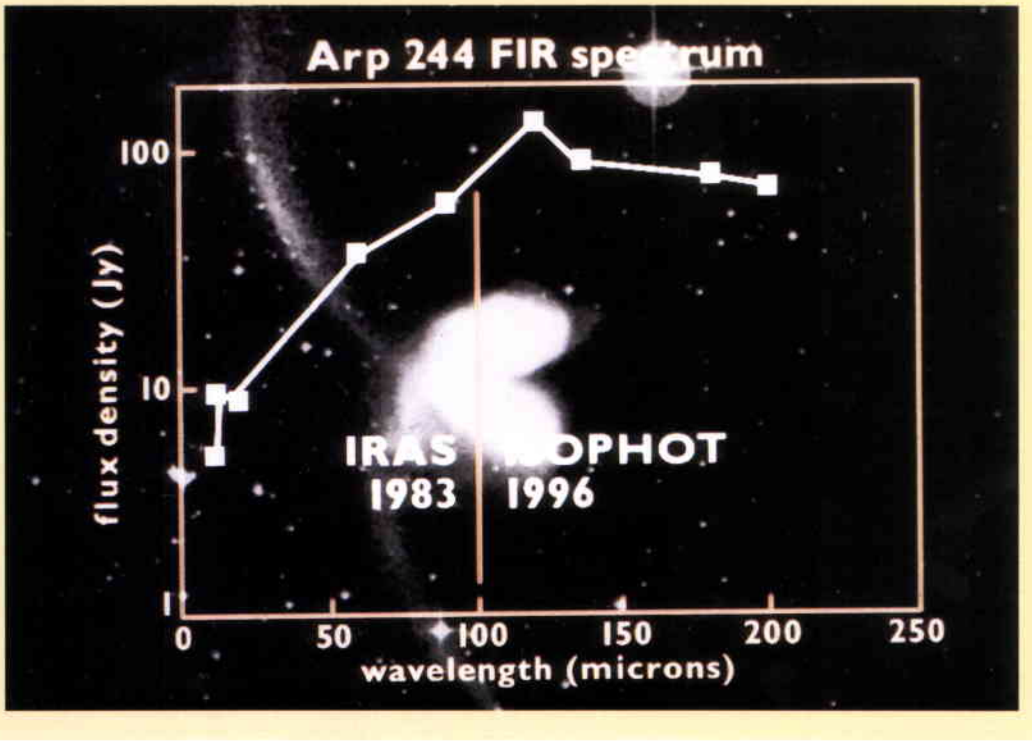

Figure 10. ISOPHOT spectral energy distribution of the colliding galaxies known as the Antennae, overlaid on a visible image

full description of the participants in the ISO Programme was given in ESA Bulletin No. 84.

The smoothness with which the Satellite Commissioning and Performance Verification Phases were executed is a tribute to the expertise, enthusiasm and hard work of the teams at ESOC, Darmstadt and Villafranca, Spain. These teams contained ESA staff, personnel from industry, contractors, scientists and engineers from the instrument teams. Additional invaluable effort and support came from teams located at the 'home' institutes and companies.

Without all of this selfless effort, the results described in this article could not have been achieved.

The data for the scientific results described in this article were obtained, reduced and analysed by members of the four instrument teams and of the Science Operations Centre.

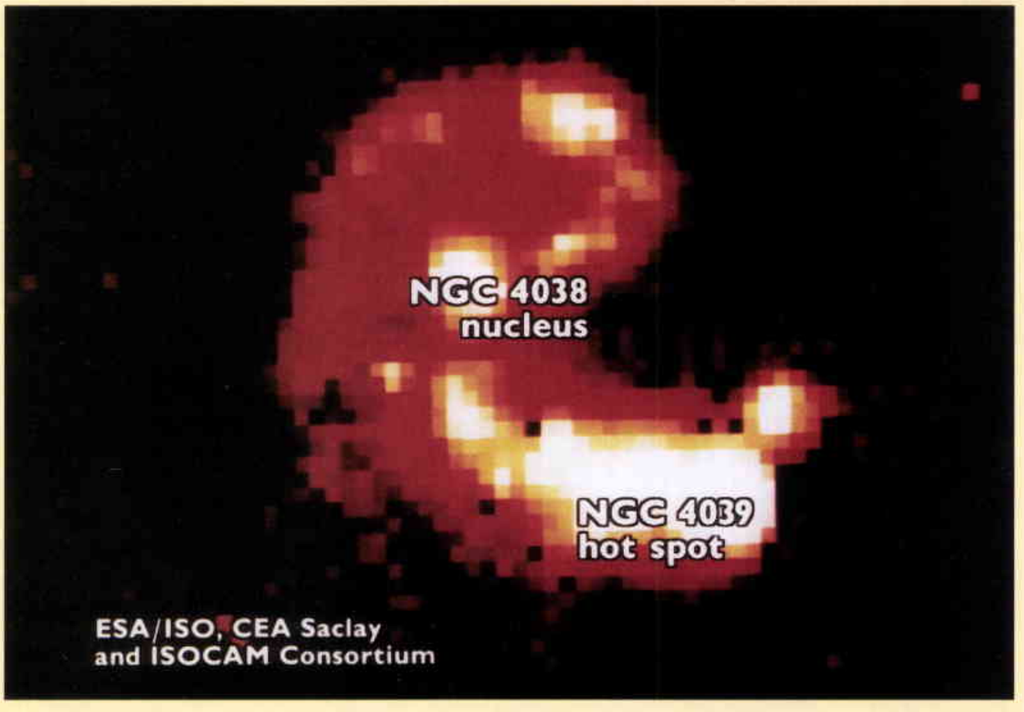

Figure 11. ISOCAM image of the colliding galaxies known as the Antennae at a wavelength of 15 microns

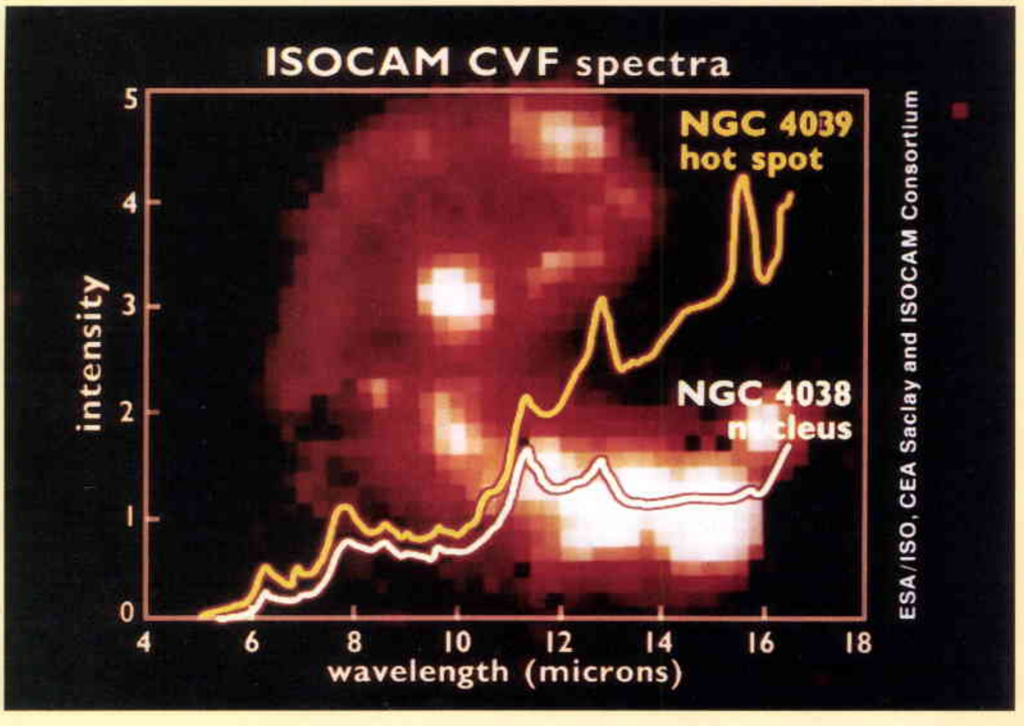

Figure 12. ISOCAM spectra of two regions of the colliding galaxies known as the Antennae

The ISO Ground Segment at Villafranca: Its Integration and End-to-End Validation

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ESA's Infrared Space Observatory (ISO) was successfully launched from the Guiana Space Centre in Kourou on 17 November 1995. Its requirements in terms of ground-segment preparation were particularly demanding due to the limited mission lifetime, which calls for highly efficient operations, the very fast pace of the ISO observations, some lasting just a few minutes, the severe pointing requirements which demand sophisticated planning, and the real-time commanding of the highly sophisticated payload of four instruments with multiple operating modes from a computer-generated, automatically executing file.

It was recognised that, given these demanding constraints, a well thought out approach to overall ground-segment integration, testing and validation would be required to ensure success. The approach that was chosen, based on the concept of end-to-end testing supported by sophisticated instrument simulators, proved highly effective. As a result, the ISO ground segment was ready to support all of the mission's operational phases in time for the spacecraft's launch.

Aerial view of the ESA complex at Villafranca

The ISO ground segment

Two different ground-segment configurations have been established to support ISO operations during the four different mission phases:

(i) The Launch and Early Orbit Phase (LEOP) system at ESOC, in Darmstadt (Germany), supporting the Operations Control Centre and the network of associated ESA ground stations at Villafranca (Spain), Kourou (French Guiana) and Perth (Australia).

(ii) A system at Villafranca, Spain, connected to the two ground stations at Villafranca and Goldstone (USA), to support the other three phases of the mission: i.e. the Satellite Commissioning Phase (SCP), the Performance Verification Phase (PV) and the Routine Operations Phase.

Control of the mission was to be transferred from ESOC to Villafranca at the end of LEOP, once the ISO operational orbit (24 h geosynchronous) had been achieved, nominally four days after launch. The Villafranca Control Centre has two co-located main elements, the Spacecraft Control Centre (SCC) and the Science Operations Centre (SOC), communicating via a routing and archiving computer known as the Operational Data Server (ODS) and housed in the SCC (Fig.1).

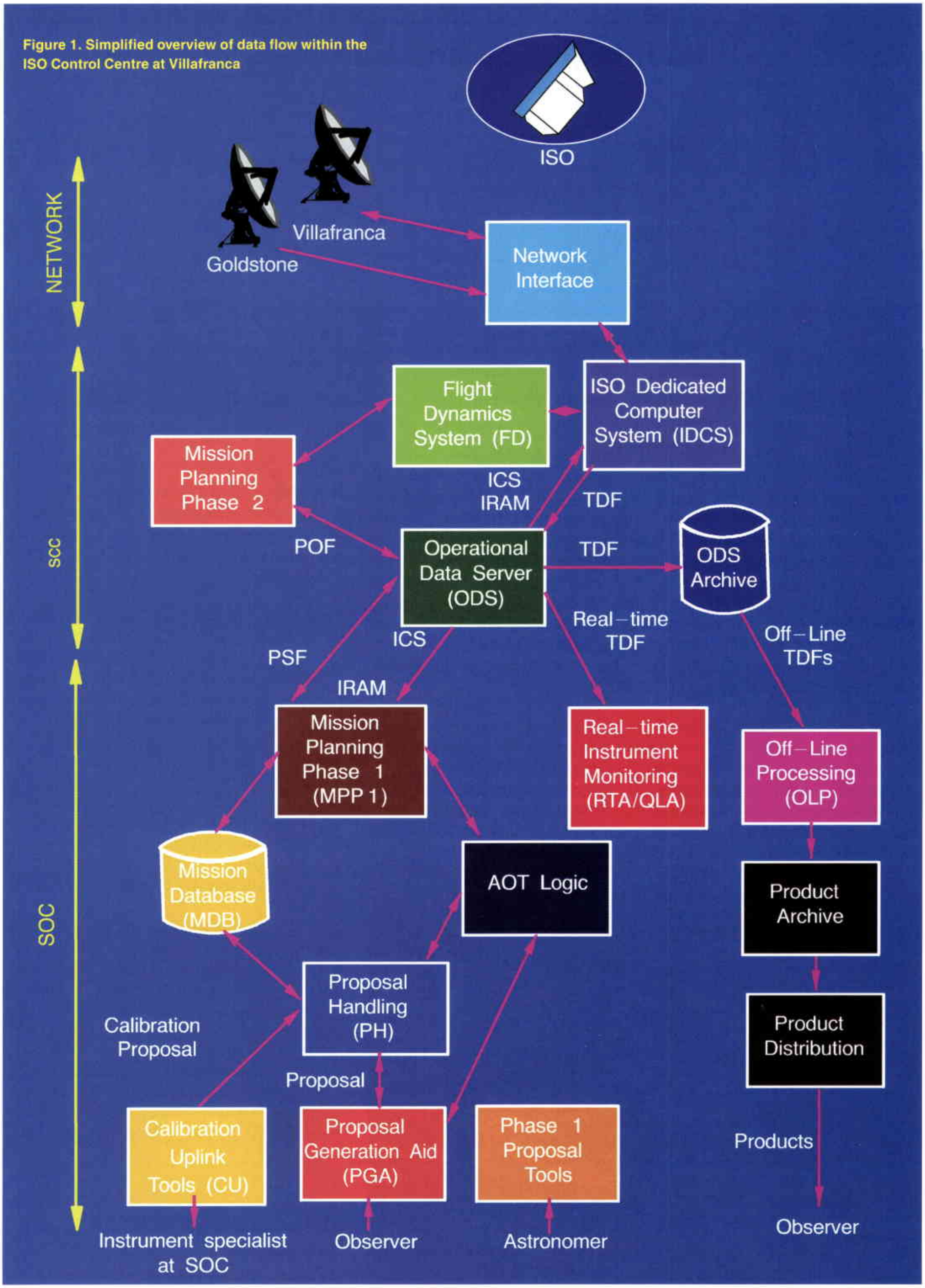


Figure 1. Simplified overview of data flow within the ISO Control Centre at Villafranca

The ground segment has been designed to support automatic operation of both the spacecraft and its on-board instruments. Under nominal conditions, satellite commanding is performed automatically from a Central Command Schedule (CCS) that is generated in advance for each ISO orbit. The CCS is based on the concept of 'operations windows', whereby time slots are allocated for all spacecraft and science instrument commanding activities during a given orbit. Typical examples are star-tracker calibration, ranging, station handovers, instrument activation/deactivation, and the scientific observations themselves.

The Central Command Schedule is generated in several consecutive steps from observations entered by Guest and Guaranteed Time Observers and validated at facilities provided at ESTEC and at NASA's Infrared Processing and Analysis Centre (IPAC), before being transmitted to the mission database:

(i) The SOC receives the outline of activities for each orbit from the SCC in the form of a Planning Skeleton File (PSF) which, inter alia, allocates windows for scientific observations.

(ii) Based on target visibility and observation priority, the SOC mission planning team constructs a Planned Observation File (POF) by inserting observations from the mission database (containing some 30 000 observations at launch) into the observation windows identified in the PSF. The result is a timeline of spacecraft pointings and instrument commands. In parallel, the SCC mission planning team inserts the commands related to spacecraft activities and instrument activation/deactivation into corresponding windows in the PSF.

(iii) At the SCC, the POF and the associated instrument command file are validated and spacecraft attitude requests are converted into uplink commands.

(iv) Finally, the SOC and the SCC commanding schedules are merged into the Central Command Schedule for each orbit.

The science and housekeeping telemetry from the spacecraft, stamped with the reception time at the ground station, is transmitted to the SCC, where the housekeeping telemetry is extracted and processed for spacecraft-control purposes. In parallel, the raw instrument (science and housekeeping) telemetry is augmented with telecommand history and ancillary data and transferred to the SOC in the form of Telemetry Distribution Formats (TDFs) across the ODS interface. These real-time TDFs are archived by the ODS and processed in the SOC at the instrument stations (one per instrument) for real-time assessment of the on-board instruments' behaviour (Real-Time Assessment: RTA) and preliminary analysis of the quality of the science data (Quick-Look Assessment: QLA).

The telemetry archived in the ODS is accessed and further processed offline by the SOC through the Off-Line Processing (OLP) system. This processing includes pipeline and

The ISO Spacecraft Control Room at Villafranca

interactive analysis and generates the final mission products, which are then archived at the SOC and distributed to the scientific community.

To increase flexibility and cope with potential spacecraft or instrument anomalies, manual commanding of the spacecraft and the instruments is possible by means of dedicated procedures available to the spacecraft and instrument controllers.

The ISO ground segment has been designed and implemented by several different groups under the overall coordination of the ISO Project at ESTEC:

- ESA's Directorate of Operations has provided the communications and ground-station infrastructure, as well as the Spacecraft Control Centre (SCC).
- ESA's Directorate of Scientific Programmes has been responsible for the development of the Science Operations Centre (SOC).
- The Principal Investigator (PI) Institutes have provided several major components, in particular instrument-specific command files and software modules to be integrated within the SOC.

The integration and validation approach
It was recognised early in the ISO Programme that the complexity of the overall ground segment (cf. Fig. 2) would make its integration and validation a very challenging task. An ISO Integration and Test Team (ITT) was therefore established in the summer of 1991 to generate and implement an overall integration and validation plan, based principally on the concept of 'end-to-end' testing, that would ensure the ground system's readiness in time for the observatory's launch.

After a slow start due in part to the unavailability of much of the ground-segment software, the team became fully operational in the second half of 1993. The intervening period was used to establish and refine the integration and validation concept, as well as the basic ground rules and responsibilities. As work progressed, the ITT's membership was broadened to include spacecraft- and science-operations representatives, as well as representatives of the Instrument Dedicated Teams (IDTs). This expansion of the ITT followed quite naturally from the progress made in the ground segment's ability to support the mission.

Once the ground system was functioning, the emphasis shifted towards performance and

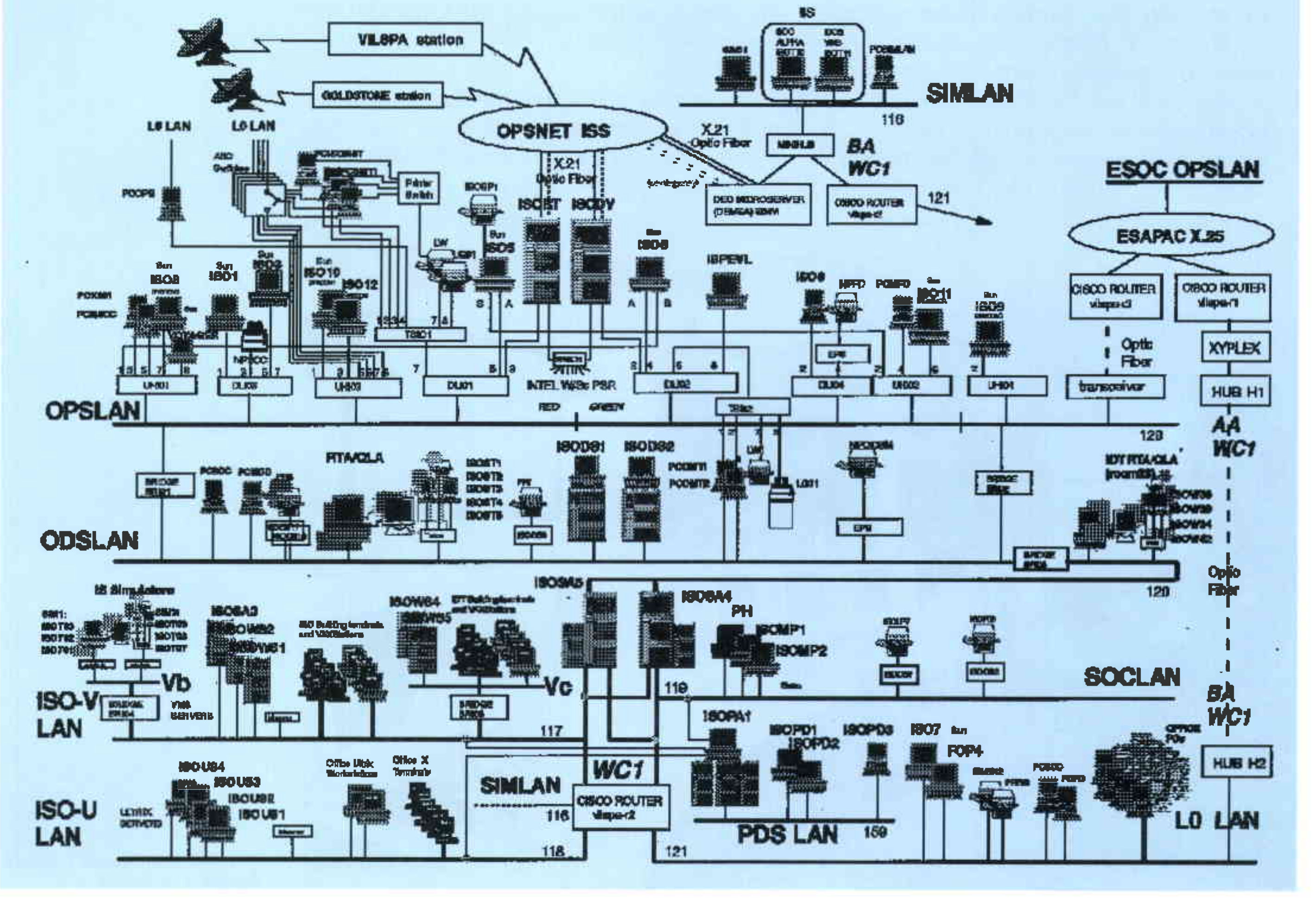


Figure 2. The ISO computers and Local Area Networks (LANs) at Villafranca

operational issues. The final ITT System Operation Validation tests and operational simulations provided early feedback on both operational aspects and system performance. In addition, they offered an opportunity for the extensive training of operational personnel and ensured a smooth transition between the validation testing and the ISO pre-launch simulation campaign at Villafranca.

The ITT approach to ground-segment integration and validation was based on the concept of comprehensive end-to-end testing with the real spacecraft, to complement the traditional system-validation and mission-readiness tests (SVTs and MRTs). The traditional approach of SVTs (validation of spacecraft control operations in terms of database contents and procedures) and MRTs (validation of the Control Centre interfaces with the network) leaves much of the ground-segment 'final tuning' to be carried out after launch. Because a tuning phase lasting for several months would have reduced the scientific return from the mission, the end-to-end tests were conceived as a means to permit dynamic and incremental validation of an overall system against the flight hardware. More and more of the SOC functional elements and the corresponding operational interfaces were included as they became available to reduce the number of problems that, with the classical SVT – MRT approach would have been detectable only after launch.

The end-to-end concept adopted consisted of establishing a validated Control Centre (SOC and SCC) communications backbone on which the applications software was incrementally integrated and validated as and when available.

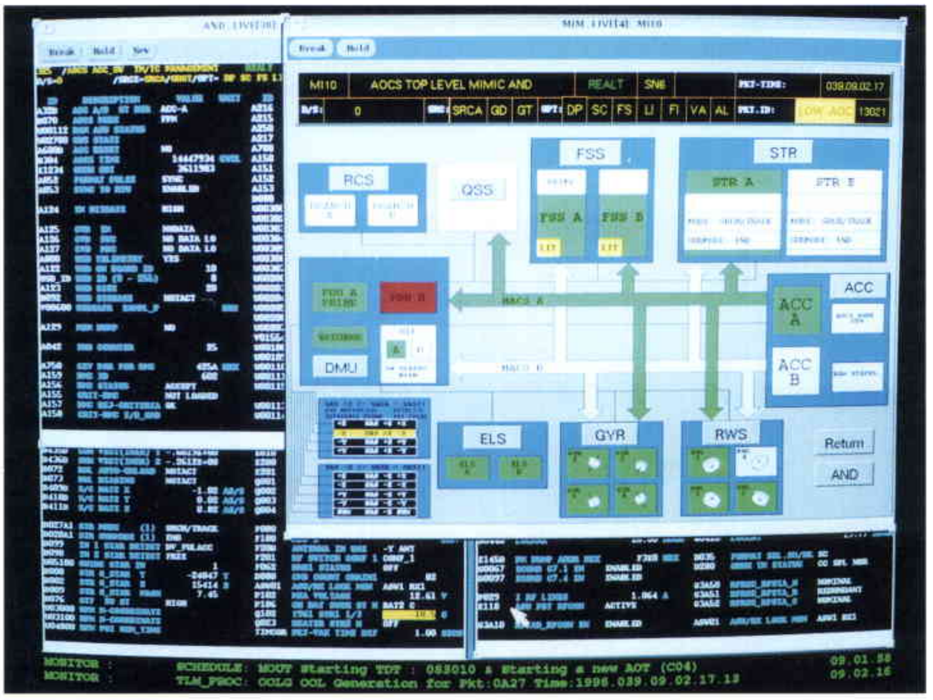
This concept called for the availability of a representative simulator that would be capable of reproducing the in-orbit behaviour of the spacecraft and its instruments. The requirement to support full-scale testing of the SOC system in both stand-alone and integrated SOC/SCC modes was beyond the capability of the test tools either available or foreseen at that time, and this led to the development of a new Integrated Instrument Simulator (IIS), starting in the second half of 1993. The IIS, development of which was completed in approximately seven months, has proved to be an essential tool in the successful validation of the overall ground segment.

The acquisition of solid 'pre-launch operational experience' was invaluable for a short-lived observatory-type mission such as ISO (planned mission lifetime 18 months), as the highly successful in-orbit-performance verification campaign of the last months has confirmed.

The end-to-end testing methodology

The Villafranca ground segment's validation was based on two levels of testing:

(i) Demonstration of correct operation of the data-transport mechanism end-to-end, i.e.
- in the 'uplink' (ground-to-spacecraft) process, from the generation of mission planning files to the generation of CCSs and subsequent acceptance and execution of the commands by the satellite, and



ISO Dedicated Computer System (IDCS) display showing the ISO AOCS top-level mimic and, in the background, alphanumeric windows for spacecraft control

- in the 'downlink' (spacecraft-to-ground) process, from the generation of scientific and housekeeping data on-board to the acquisition, processing and filing of the telemetry by the SCC and the generation of TDFs for subsequent processing by the SOC real-time system.

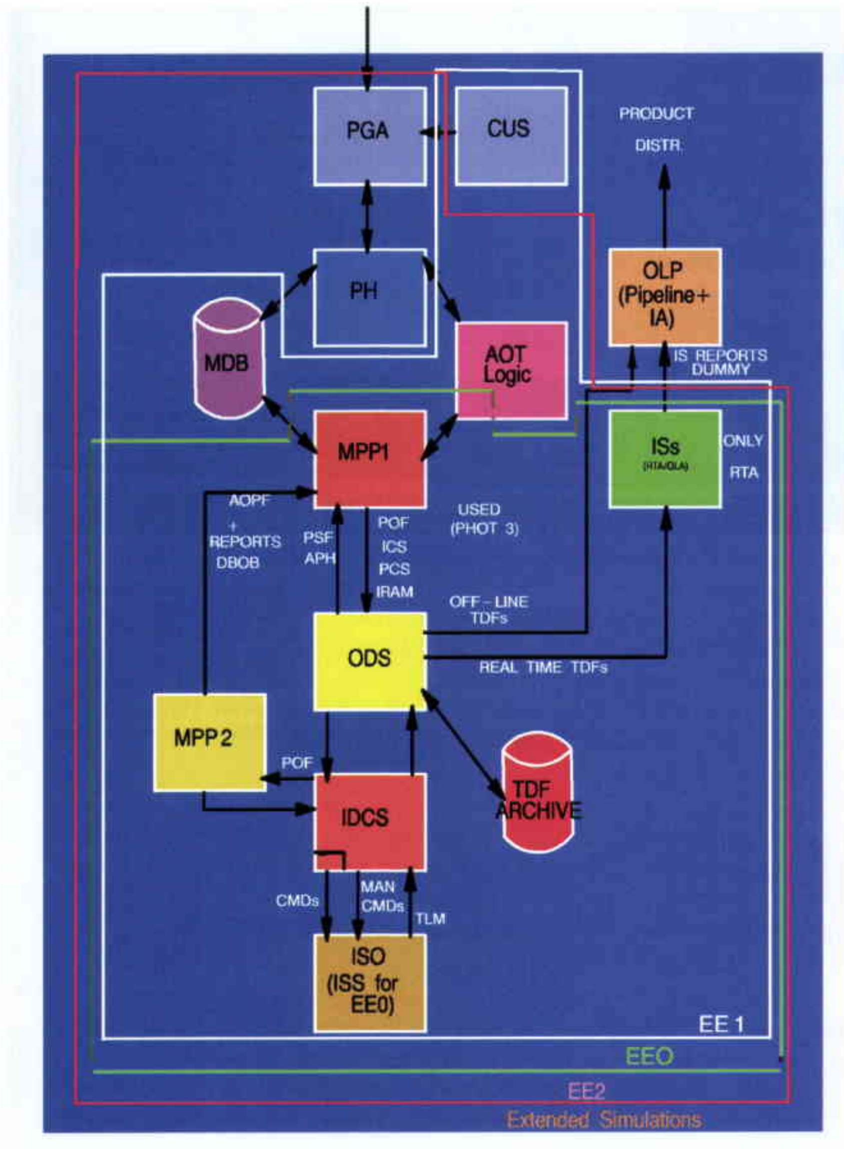
This first level of testing would demonstrate the ground segment's ability to operate the spacecraft properly via the automatic schedule (CCS), including flight-dynamics operations, as well as through manual commanding.

(ii) Demonstration of proper operation of:
- the automated SOC processing of user-requested observations into a properly timed sequence of detailed instrument commands

- the instrument activation/operation/de-activation command sequences provided by the Principal Investigator institutes
- the joint SOC/SCC recovery procedures in response to anomalous behaviour of spacecraft or instruments
- the SOC processing of scientific instrument data into standard products that can be dispatched to the scientific community.

The objectives of the first level of testing were met in the first end-to-end test (EEO) during March/April1994. The objectives of the second level were largely achieved in the second (EE1) and third (EE2) end-to-end test series conducted from December 1994 through February 1995 and in April/March 1995, respectively. Although EE2 was originally conceived as an 'all bugs fixed' repetition of EE1, actual schedules and programmatic constraints forced EE1 and EE2 to be complementary in the sense that EE1 could only be used to validate about half of the envisaged instrument operational modes, leaving EE2 to validate the rest. The remaining ground-segment functionalities, mostly involving SOC/SCC and SOC-internal, non-real-time interactions, were pre-tested in the period between EE2 and the beginning of the simulation campaign at Villafranca. The final validation was achieved during an intensive set of joint SOC/SCC simulations in July/August 1995.

Figure 3. The ISO ground-segment elements involved in the various end-to-end tests and the extended simulations



The ground-segment elements involved in the various EE tests are shown in Figure 3.

EEO

The first end-to-end test sequence was performed twice:
- in April 1994, interconnecting the ISO SCC development environment at ESOC in Darmstadt (D) with the SOC development environment at ESTEC in Noordwijk (NL) via a low-speed communication line, and
- in June 1994, repeating the previous test with the SOC and SCC operational equipment having been moved to and integrated in Villafranca, to verify that no degradation had been introduced by the re-installation and on-site connection of the systems.

Each test lasted five days and was performed using the IIS. Both tests were successful and the objectives set for this first level of testing were achieved. A total of 53 Software Problem Reports (SPRs) were raised, all of which were classified and prioritised according to their importance for the subsequent EE tests.

EE1

This second set of end-to-end tests was carried out on six consecutive days in February 1995, each day simulating a typical ISO orbit. The Villafranca Control Centre was connected directly to the ISO flight model at ESTEC in its checkout environment. The Test and Simulation Assembly provided simplified in-orbit conditions for the observatory's Attitude and Orbit Control System (AOCS), including provision of a single guide star for the simulation of spacecraft manoeuvre execution. The first three orbits were dedicated to the validation of performance-verification observations, the last three to the testing of observations in standard instrument modes of operation (defined through Astronomical Observation Templates: AOTs).

Deficiencies were highlighted in several areas during the EE1 testing, including: connectivity problems between Villafranca and ESTEC, database inconsistencies, and problems in both operational and support software. A total of 91 SPRs were raised, but many of these

The ISO Science Operations Room at Villafranca

problems were already solved prior to starting EE2.

A great deal was learned in EE1 from an operational point of view, particularly regarding the ground segment's ability to recover from errors, the manual operation of the spacecraft and instruments, and the resumption of automatic commanding from the CCS after an interruption.

EE2

The EE2 testing consisted of running seven simulated orbits from the ISO Control Centre in Villafranca with the ISO flight model at ESTEC. All orbits were dedicated to testing the various instrument operational modes (defined through the AOTs), but included some additional flight-dynamics tests. This entire series of tests, including rehearsals, dry runs, and the actual tests with the satellite, was completed in just five weeks, starting at the end of March 1995.

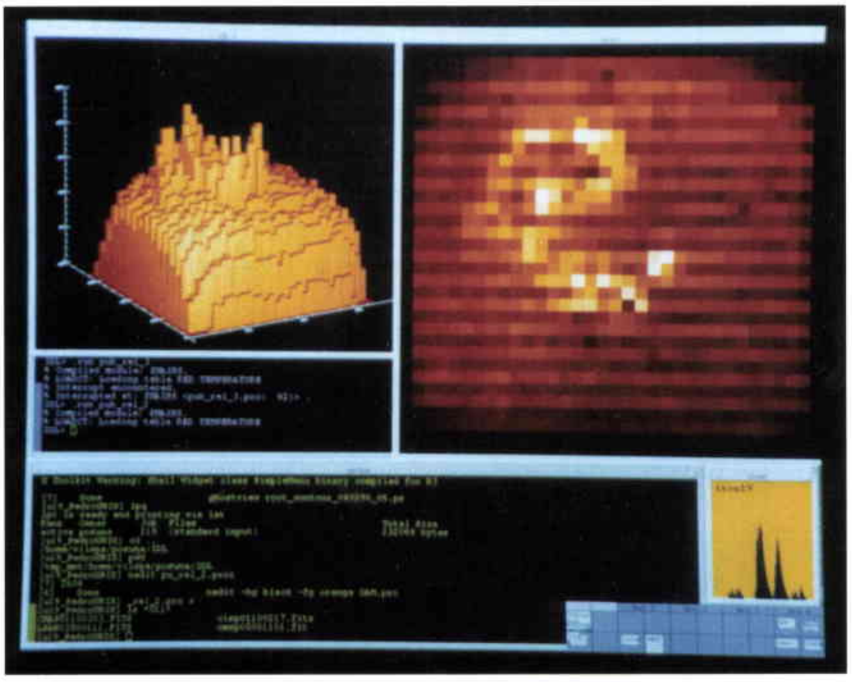
In the EE2 tests themselves, emphasis was put on the operability of the system, particularly on the SOC side. Several errors were detected and a total of 183 SPRs were issued, and addressed in order of priority.

At the end of EE2 it was concluded that, although functionally ready to support performance verification and routine operations of the ISO mission, from an operational point of view there were still major deficiencies in the system. These were rectified before the start of the extended simulations in July 1995 thanks to the dedication of all groups involved involved in the ground segment's preparation.

Extended simulations

Following EE2, the ITT's mandate was expanded to define and conduct a series of extended simulations of ISO operations during July/August 1995. These simulations were run in two steps, with the objectives of:

- validating the procedures to be exercised during critical SCP stages, in particular those orbits during which the ISO focal-plane geometry calibration was to be conducted
- providing further training for members of the operations teams by simulating a number of orbits of the instrument performance verification phase



Off-line processing display for an ISOCAM observation, taken after launch. The picture shows a two-dimensional image display of flux/pixel and the corresponding three-dimensional histogram for images collected from NGC 4038/39 ('The Antennae')

Summary of ISO Key Events

Mid 1991	Establishment of ISO core integration and Test Team
Feb. 1992	Test of the Operational Data Server Interface
Apr. 1994	EE0 Test ESOC–ESTEC
Jun. 1994	EE0 repeat at Villafranca
Jan. 1995	EE1 Dry–run (with simulator)
Feb. 1995	EE1 (with spacecraft)
Apr. 1995	EE2 Dry–run (with simulator)
May 1995	EE2 (with spacecraft)
May 1995	Extension of ITT terms of reference
Jul. 1995	Extended simulations phase 1
Aug. 1995	Extended simulations phase 2
Nov. 1995	ISO LAUNCH

– running two round-the-clock simulations of the routine mission phase, lasting four and eight days, respectively.

By the end of the second set of extended simulations, substantial improvements had been made in all areas of operational readiness. Because of the demands put on the operations teams during the first half of 1995, it was feared that, rather than further increasing operational readiness, a third set of extended simulations so close to the launch might have been counter-productive.

Conclusion

In the event, the integration and validation of the ISO ground segment did indeed turn out to be a very challenging task. Despite a very tight schedule, however, and quite a few unpleasant surprises encountered along the way during the various phases of testing, the necessary validation was completed on time and within the resources allocated.

The ultimate success of the simulation campaign, namely the smooth satellite operations after launch, and the high standard of operation of the Villafranca ISO Control Centre itself since the very beginning of the mission, all bear witness to the validity of the overall approach that was adopted.

The History of the SOHO Mission

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The roots of the SOHO mission and the story leading to the comprehensive observatory that the spacecraft is today are summarised here. Now fully operational in its halo orbit around the first Lagrangian point (L1) between the Earth and the Sun, SOHO is providing the international scientific community with the unique opportunity, and also challenge, of understanding the Sun and heliosphere as one complex, global system. It is a superb tool with which to investigate our daylight star and its circumstellar environment, from the Sun's centre, through its visible surface and tenuous corona, and out into the heliosphere to distances corresponding to more than ten times the orbital distance of the Earth.

Introduction

The Solar and Heliospheric Observatory, SOHO, is the most comprehensive space mission ever devoted to the study of the Sun and its nearby cosmic environment known as the heliosphere. From the vantage point of a halo orbit around the first Lagrangian point, L1 (cf. Fig. 1), SOHO's twelve scientific instruments observe and measure structures and processes occurring inside as well as outside the Sun, and which reach well beyond the Earth's orbit into the heliosphere. The SOHO spacecraft is immersed in the solar-wind streams and provides an extremely stable platform – stabilised to a fraction of one arc-second (an angle equivalent to the breadth of a hair viewed from 20 m away!) – for these instruments, which are small observatories in their own right.

The observing programme for the ensemble of instruments, the most modern in their categories, is established and coordinated through a sequence of monthly, weekly and daily reviews. In this way, orderly long-term planning is achieved, yet the SOHO investigators can also respond to 'targets of opportunity' offered by the ever-changing conditions in the solar atmosphere, and exploit new knowledge gained (or lessons learned) from earlier SOHO observations: critical observations can be confirmed or improved upon without undue delay.

The SOHO mission is an international collaboration between ESA, European national authorities and NASA. ESA took the lead in the collaboration between the two large agencies by procuring the spacecraft (including integration of the twelve instruments and environmental testing of the satellite) through European Industry. The instruments were built under the leadership of Principal Investigators – nine of them funded by European national authorities, and three by NASA. Further support was given by Co-investigators and Associated Scientists with European and US national funding. NASA provided the SOHO launch aboard an Atlas-2AS vehicle and it also takes care of mission operations as well as communications with the satellite via the Deep Space Network. Overall responsibility for the mission remains with ESA.

Solar physicists and engineers from universities and scientific institutions on both sides of the Atlantic who were involved in the design, construction and calibration of the experiments and in the preparations for the data analysis, are also participating in the scientific operations.

The circa 250 original Principal Investigators, Co-Investigators and Associated Scientists are now, as the data are coming in, being joined by an even larger number of scientists who are participating in the observations and making use of SOHO data in their work.

On 14 February, SOHO reached its location at Lagrangian point L1, 1.5 Gm from Earth. As new fundamental knowledge about the Sun and heliosphere now becomes available, this is an opportune moment to recall the steps that led to the approval of this first mission of the first Cornerstone of ESA's Long-Term Plan Horizon 2000 fully devoted to studying the Sun.

Accordingly, we will address here the questions:

- What were the origins of the SOHO mission?
- How was the international framework that resulted in the current comprehensive study of the Sun established?
- What developments in ESA's planning and the negotiations with NASA eventually led to SOHO being approved as part of the first Horizon 2000 Cornerstone?

The origins of the SOHO mission

The foreword to the report on the SOHO Phase-A Study prepared for the presentation of candidate missions for project selection in January 1986 summarises very well the developments that took place during the most decisive approval phases. The first three paragraphs read:

- *'SOHO... was proposed to ESA by M. Malinovsky-Arduini, H.F. van Beek, J.P. Delaboudinière, M.C.E. Huber, P. Lemaire and B. Patchett in November 1982 in response to a Call for Mission Proposals. After review of the competing proposals by the scientific advisory bodies in December 1982, SOHO was recommended for an Assessment Study, which was conducted between February and August 1983.*

  Upon the recommendation of the SSAC (Space Science Advisory Committee), the SPC (Science Programme Committee) approved in November 1983 the Executive's proposal to proceed with a Phase-A Study for SOHO.

  At the same time, it was recommended to explore the possibility of including SOHO and Cluster in an International Solar-Terrestrial Physics (ISTP) Programme to be undertaken jointly by ESA, NASA and ISAS. In May 1984, the Survey Committee identified SOHO as a component of the Solar-Terrestrial Physics (STP) 'Cornerstone' of the ESA long-term programme 'Space Science: Horizon 2000'.'

These paragraphs reveal that SOHO was proposed 13 years before its actual launch, but that within less than three years it had become part of a Horizon 2000 Cornerstone. They do not, however, reflect the fact that the roots of SOHO were laid in earlier studies, namely those of GRIST (Grazing Incidence Solar Telescope) and DISCO (Dual Spectral Irradiance and Solar Constant Orbiter). It is the combination of the objectives of these two missions that constitutes the core of the SOHO mission.

Indeed, most ESA missions – especially those in 'new' fields – are the result of an evolution rather than a single proposal. Often such studies eventually involve the communities of several space-science disciplines. Aligning these communities behind one coherent proposal involves several steps and can thus take quite some time.

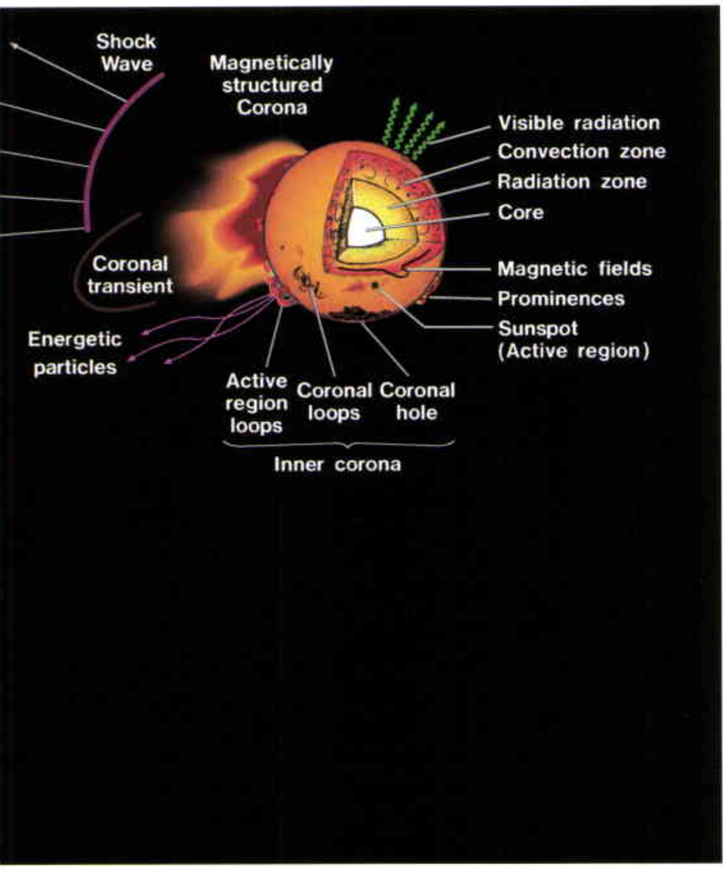


Figure 1. SOHO orbits around the first Lagrangian point L1, which is located on the Earth – Sun line, 1.5 x 10^6 km (i.e. 1.5 Gm) from the Earth. This distance corresponds to 5 light-seconds, or 0.01 Astronomical Units (AU), i.e. 1% of the way from the Earth to the Sun

In fact, already in June 1976, GRIST had been competing with a 'Solar Probe' (as well as other studies involving other disciplines) for further study, under Phase-A. Solar Probe envisaged a set of instruments on a spacecraft that would approach the Sun once to within four solar radii. Although its Assessment Study cited four scientific disciplines interested in the mission: (i) solar wind and space plasma, (ii) solar atmosphere, (iii) solar and stellar interior, and (iv) experimental gravitation and relativity, Solar Probe was not followed up at the time.

The GRIST study, on the other hand, went into Phase-A. It foresaw a grazing-incidence telescope (feeding several focal-plane instruments) that was to be mounted on the Instrument Pointing System (IPS) and flown as part of a Spacelab payload. One of the reasons for GRIST's preference over Solar Probe was that the wavelength range accessible through grazing-incidence optics is particularly powerful for spectroscopic diagnostics of the hot outer solar atmosphere. Spectroscopy in this domain had long been neglected on major solar satellites (Skylab 1973, Solar Maximum Mission 1980, Yohkoh 1991), partly because of experimental difficulties. (In fact, an instrument covering the extreme ultraviolet, which had been under development in the USA, had to be abandoned due to severe cost overruns. The pressure to develop a similar instrument was therefore very strong).

For the Phase-A Study of GRIST, a team of scientific consultants (A. Gabriel, U. Grossmann-Doerth, M. Huber, M. Malinovsky, G. Tondello and F. van Beek) was selected through an open solicitation in the scientific community. This team worked together with ESA staff (G. Haskell and G. Whitcomb) in writing specifications for the industrial study, which was carried out by the British Aircraft Corporation (later BAe) together with the UK National Physical Laboratory and the University of Leicester. GRIST was at that time designated for multiple flights on Spacelab, mounted on the Instrument Pointing System (IPS). Its smallest picture element in the ultraviolet was planned to be 1 x 1 arcsec^2 – a performance somewhat exceeding even that of SOHO.

Following the Phase-A Study (1976-78), accommodation studies were made with the intention of flying GRIST alongside NASA's Solar Optical Telescope (SOT) on Spacelab. V. Domingo joined the above group as Study Scientist during that time.

Like the Solar Probe, GRIST did not make it to project selection either: being based on a collaboration with NASA, in early 1981 it became a victim as part of ESA's response to NASA's unilateral cancellation of the US probe in the 'International Solar Polar Mission' (ISPM, the former 'Out-of-Ecliptic Mission', now called 'Ulysses'); GRIST was 'moth-balled'. Fortunately, however, restricted studies (concentrating mainly on the spacecraft interface) of the main spectrometers of GRIST were further supported by ESA.

In the course of 1980, many leading solar physicists took part in two international conferences at which prospects for space observations of the Sun were discussed. The first, an ESLAB Symposium dealing mainly with aspects of the solar irradiance, was held in Scheveningen (NL) in September 1980; the second, on 'Solar Physics from Space' and addressing mainly coronal observations, was organised in Zurich (CH) in November 1980.

In July that year, in response to an ESA Call for Mission Proposals, a group of French and Belgian scientists (R.M. Bonnet, D. Crommelynck, J.P. Delaboudinière and G. Thuillier) proposed a mission dedicated to the study of

Scientific Aims and Capabilities of SOHO

SOHO aims to answer the following three fundamental questions about the Sun:
- What is the structure and what are the dynamics of the solar interior?
- Why does the corona – the tenuous outer solar atmosphere that can be seen with the naked eye during eclipses and which is much hotter than the solar surface – exist, and how is it heated?
- Where and how is the solar wind, i.e. the particle streams which represent the solar mass loss, accelerated?

It also addresses the influence of the Sun on its environment, the heliosphere, as well as the ecliptic plane in which the planets and their moons orbit the Sun.

The orbit of SOHO around the first Lagrangian point, L1, at a distance of 0.01 Astronomical Units from Earth (cf. Fig. 1), is central to the mission design: it provides a perfect vantage point for the investigations required to answer the above three questions. The satellite is located outside the absorbing, blurring and scattering terrestrial atmosphere, and outside the magnetic shield of the Earth's magnetosphere. Consequently, SOHO has access to the entire electromagnetic and particle spectrum of the Sun. In addition, observations are continuous, as there are no occultations of the spacecraft's line of sight. Furthermore, the relative velocity between satellite and Sun is small and varies slowly, a key element as discussed in the DISCO studies for helioseismology velocity measurements.

For all of these reasons SOHO, designed as a three-axis-stabilised spacecraft continuously pointing to the Sun with a stability that has turned out to be even better than the design value of 1 arcsec, is an ideal platform. It permits uninterrupted investigation of the ultraviolet and soft X radiation and the particle streams that are formed in the hot outer layers of the Sun's atmosphere and optimum conditions for probing the solar interior by the method of helioseismology.

In loose analogy to the above three basic questions to be answered by the mission, SOHO carries three payload segments:
- **the helioseismology payload:** this consists of two velocity spectrometers (GOLF and SOI/MDI) and several radiometers (VIRGO) that can measure the velocity and intensity of solar oscillations, investigate non-periodic variations of the solar 'constant', and determine its absolute value.
- **the coronal payload:** this consists of a number of remote-sensing instruments (CDS, EIT, LASCO, SUMER, UVCS) designed to study the physical structure and dynamics of the upper solar atmosphere (i.e. the so-called 'chromosphere', 'transition zone' and 'corona', out to 30 solar radii); it also surveys (out to at least 10 AU) the ionised cavity which the solar wind 'burns' into the neutral 'stellar wind' that traverses the heliosphere (SWAN), and
- **the solar-wind and particle payload:** this contains several mass-spectrometers (CELIAS) and medium- and high-energy particle analysers (COSTEP, ERNE) to study the solar wind in-situ, near the Earth's orbit (more precisely at 0.99 AU), and to investigate solar as well as cosmic energetic particles.

As noted earlier, the relationship between the investigations of the three questions listed initially and the three payload segments is not a strict one, because studies of the acceleration of the solar wind and of the structure of the corona require both remote- and in-situ sensing of the solar-wind streams.

spectral irradiance and the solar constant. This was considered an important objective in view of the possible climatic effect of a long-term variation in solar irradiance.

Simultaneously, the heliospheric community was becoming aware of the fact that, although the solar wind in the ecliptic plane had been almost continuously monitored for the past fifteen years, there was every chance that this surveillance might cease before ISPM. This anxiety was expressed in a resolution unanimously adopted at the ISPM Science Working Team meeting in October 1980. They urged that priority be given to complementary baseline measurements by a spacecraft in the ecliptic at about 1 AU distance during the heliographic high-latitude passes of the ISPM spacecraft, at that time envisaged for 1989/1990 (the actual passes occurred five years later).

At nearly the same time, in the austral summer of 1979 – 1980, a group of French and American physicists observed the Sun continuously from Antarctica between 31 December 1979 and 5 January 1980. They thereby succeeded in measuring the global velocity oscillations of the Sun with an unprecedented signal-to-noise ratio. These historic observations led to the decision to include helioseismology velocity observations on-board DISCO, as are now being performed on-board SOHO with the GOLF experiment.

At a meeting between the late P. Delache from the Nice Group and R.M. Bonnet at the Institut d'Astrophysique in Paris, it was proposed to locate DISCO at the L1 Lagrangian point between the Sun and the Earth, which would be an ideal observing site for these velocity observations because of the spacecraft's low radial velocity relative to the Sun. A miniaturised version of the South Pole experiment (then weighing several hundred kilos) could be embarked as part of DISCO's payload, provided its weight could be considerably reduced.

In addition, the potential for helioseismology of solar brightness oscillations, as evidenced by the high quality of the solar-constant data obtained by the ACRIM instrument on SMM, offered a unique asset to the mission which could, for the first time, attempt to detect the Sun's global oscillation modes and shed new light on the intriguing solar neutrino deficit issue. An instrument measuring brightness oscillations would therefore add a substantial helioseismology element to the radiance and irradiance instruments. Accordingly, DISCO's model payload was extended to contain a set of photometers and absolute radiometers to perform measurements of the total and spectral irradiance in selected bands and to detect solar oscillations in visible light, as are now being performed by the VIRGO experiment onboard SOHO.

DISCO was also going to carry a far-ultraviolet spectrometer to study coronal holes. It was conceived as a fairly small and cheap spin-stabilised spacecraft, weighing no more than 520 kg (dry weight) and, in the minds of its proponents, it was supposed to prove that ESA could also undertake small and inexpensive missions (already in 1980!).

A first assessment was made and the results published in the Assessment Report in May 1981. At its meeting in June 1981, the Science Advisory Committee (SAC) recommended a re-assessment of the mission, addressing the following topics in order of priority: (i) solar seismology (brightness and velocity), (ii) baseline in-ecliptic measurements in support of the ISPM mission, and (iii) measurements of the solar irradiance. The SAC also insisted that the overall cost of the revised DISCO mission must not exceed that of the original proposal. The resulting model payload had been selected to be as consistent as possible with these objectives (Fig. 2).

The science team for the study was made up of A. Balogh, R.M. Bonnet, P. Delache, C. Fröhlich and C. Harvey. D. Wyn-Roberts was the study engineer from ESTEC and V. Domingo the study scientist. The SPC decided in February 1982 to proceed with a Phase-A Study, which was conducted between April and November 1982 by British Aerospace.

Upon completion of this study, DISCO had remained a relatively inexpensive spinning satellite, very similar in fact to a Cluster satellite. At its meeting in January 1983, the Solar System Working Group preferred DISCO to a competing Mars mission called 'Kepler'. However, DISCO eventually lost out to ISO (the Infrared Space Observatory) in the final evaluation by the Space Science Advisory Committee, and thus ISO was approved as a new project by the Science Programme Committee in March 1983.

ISO, eventually launched in November 1995, just two weeks before SOHO, was an exceptional case. It was proposed by the 'new' infrared community, and went straight from mission proposal via Assessment and Phase-A Studies to approval as a new project. Although selected before Horizon 2000 and thus carried as a pre-selected 'medium-size mission' in the Horizon-2000 Plan, its overall cost was close to that of a Cornerstone today.

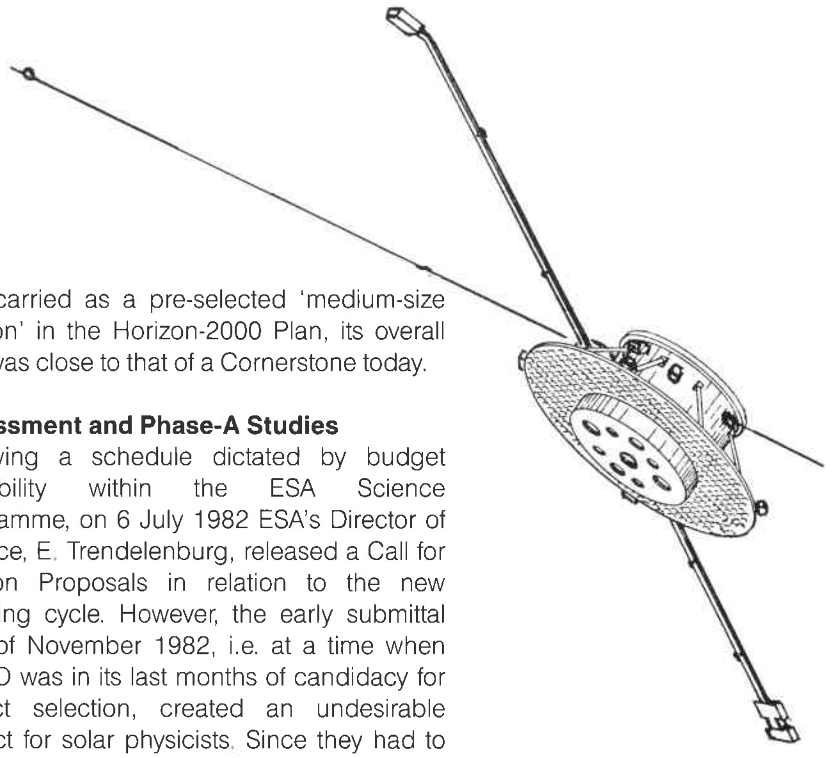


Figure 2. The concept DISCO spacecraft at the time of the reassessment study

Assessment and Phase-A Studies

Following a schedule dictated by budget availability within the ESA Science Programme, on 6 July 1982 ESA's Director of Science, E. Trendelenburg, released a Call for Mission Proposals in relation to the new planning cycle. However, the early submittal date of November 1982, i.e. at a time when DISCO was in its last months of candidacy for project selection, created an undesirable conflict for solar physicists. Since they had to submit the proposal for SOHO before a decision on DISCO had been taken, they would automatically lessen the chances of DISCO's selection, or might even be told that no new solar mission was needed until a decision on DISCO was available. It was therefore proposed to ESA, by R. Bonnet, M. Huber and A. Gabriel among others, that the call for new mission ideas should be postponed until after the selection of the next project (which, as mentioned above, took place in March 1983). However, the budget-availability deadline could not be missed and ESA declined to modify its schedule.

As a consequence, the solar-physics community started discussing a new mission which would combine some of the objectives of GRIST and of DISCO. Initially, the model payload of the new mission on a spacecraft in low Earth orbit consisted primarily of high-resolution ultraviolet spectroscopic equipment and, accordingly, the mission was dubbed the Solar High-Resolution Observatory, or SOHO (but with 'high-resolution' not yet replaced by 'heliospheric'). This mission proposal was motivated by the persistent lack of solar investigations in the extreme-ultraviolet (or more precisely, in the grazing-incidence) domain, as well as by then recent, enigmatic measurements of Doppler-shifted coronal emission (implying a solar-wind outflow starting already in the inner corona). In addition, innovative measurements of transverse coronal outflows by the so-called 'Doppler-dimming method' had just been demonstrated. Moreover, the advantages of placing a coronal payload on a free-flyer like SOHO (with a mission duration of at least a few years) rather than on even a series of ten-day Spacelab flights had been dreamt of during the GRIST study.

Although the scientists involved in the SOHO proposal (who were primarily interested in solar physics) did not wish to be seen to be jeopardising the chances of DISCO's potential selection, they agreed with their colleagues to envisage including the helioseismology objectives in those of the new mission at a later time. In that case SOHO would be placed at a Lagrangian point outside the magnetosphere and could then be renamed the Solar and Heliospheric Observatory if DISCO was not selected.

In December 1982 it was recommended that SOHO (in its high-resolution version) be pursued as an Assessment Study. In order to create a larger base for an eventual project, it was recommended by the Solar System Working Group that a particle payload segment be included in the model payload, as in DISCO's case. V. Domingo and D. Wyn-Roberts became study scientist and engineer, respectively, the latter being succeeded by J. Ellwood during the Phase-A Study.

During the first months of the SOHO study, in February 1983, it became clear that: (i) helioseismology should definitely be added to the set of spectroscopic solar telescopes forming the original payload; (ii) SOHO should, like DISCO, be placed in a halo orbit around L1 in order to be compatible with the helioseismological objectives, and (iii) in the new orbit, the 'particles-and-fields' instruments should be devoted to solar-wind composition measurements, to the study of solar energetic particles, as well as to the investigation of waves in the interplanetary medium. The science team, composed of H.F. van Beek, P. Delache, M. Huber, M. Malinovsky-Arduini, B. Patchett, H.B. van der Raay and R. Schwenn, already reflected this multi-disciplinary approach.

The basis for a NASA involvement

The studies of DISCO and SOHO coincided with the cancellation by NASA of their ISPM satellite and its aftermath. This was a time of extreme tension between Europe and the USA, and there was little interest in ESA in starting a new cooperative venture with NASA, which explains why DISCO and SOHO (in its Assessment Phase) were studied as purely European missions.

This is not to say that the scientific communities on opposite sides of the Atlantic did not discuss future potential cooperation on missions whose objectives were very similar. For example, NASA had a mission to study the interior of the Sun, the Solar Internal Dynamics Mission, whose objectives were indeed in the spirit of DISCO, with probably more emphasis on the study of the solar dynamics. After a meeting organised by NASA in early 1982 in Boulder, at which most of the active US scientists in the field were present, together with the DISCO scientists, it was decided that a special study group would be convened to define more precisely the aims of this mission.

NASA also conducted a definition study of a Solar Interplanetary Satellite (SIS) carrying the payload of their cancelled ISPM spacecraft and operating in a drift orbit at 1 AU some 90° behind the Earth. SIS was under consideration for a new start in NASA's 1984 Fiscal Year, but was never approved.

In the course of the discussions that took place between European and US scientists, the latter insisted that DISCO should include a high-resolution imaging instrument (the equivalent of what is now the MDI on SOHO) in order to study the high-order modes of the velocity oscillations. They strongly favoured transforming DISCO into a three-axis-stabilised satellite, which unfortunately would have put the project into the class of expensive missions, an option that was of course strongly opposed by the Europeans. In addition, a controversy developed on the NASA side, which was not fully convinced of the need to go into space to perform helioseismology observations when excellent results could be obtained from the ground, as demonstrated by the South-Pole observations. This controversy lasted for quite some time until NASA (D. Bohlin) recognised in the summer of 1983 at a meeting in Snowmass (Colorado) that space-based measurement would offer much better observing conditions and a strongly enhanced signal-to-noise ratio, as SOHO is proving today.

As the ISPM crisis slowly settled down, it was proposed that SOHO should be pursued with two potential launchers in mind (Ariane and the Space Shuttle). As a result, both the European and the US solar space communities could identify with the mission. Thus, the Phase-A Study was initially made with the participation of US scientists, with the support of NASA. This was the so-called 'ISTP-phase' (named after the International Solar-Terrestrial Physics Programme). When it became clear, some time before the end of the study, that NASA was not able to obtain a new start for the SOHO mission, a rider study for a purely European mission was performed. The results of this study for a European SOHO were those presented at the time of project selection in early 1986.

Before this date, there were several activities of great significance for the fate of SOHO, namely the International Solar-Terrestrial Working Group (that led to a Joint ESA/ISAS/NASA Planning Group for the ISTP Programme being set up) as well as the preparations for the long-term scientific programme Space Science: Horizon 2000, to which we will now turn.

The International Solar-Terrestrial Physics Working Group

At one of the regular consultation meetings between ESA and NASA in June 1983, it was agreed that an integrated look should be taken at the large number of missions under study in the USA, Europe and Japan in the area of solar-terrestrial physics. NASA and ESA therefore organised a preparatory meeting in September 1983, to which the Japanese Institute for Space and Astronautical Science (ISAS) was invited.

After extensive discussion and a rather painful rationalisation process, the 'International Solar-Terrestrial Physics (ISTP) Programme' (Fig. 3) was formulated. It embodied a reduced version of NASA's previous 'Open' programme, now consisting of four spacecraft – 'Wind' (measuring the solar wind and space plasma properties near the Lagrangian point L1; cf. Fig. 1), 'Equator' and 'Polar' (in near-Earth orbits) and 'Geotail'. New 'add-ons' were Cluster and SOHO. The late Stanley Shawhan, who chaired this trilateral meeting and masterfully guided the rationalisation process, must be considered *spiritus rector* of the ISTP programme.

It was argued in that preparatory meeting, by G. Haerendel, that SOHO and Cluster ought to be flown together: both were addressing the same physical structures and processes by remotely sensing the coronal plasma, by in-situ measurements of the solar wind, and by in-situ investigations in three dimensions of the magnetospheric plasma. It was pointed out, however, that the two missions were under Phase-A study only and that, given the usual ESA selection process, it would be almost impossible for both SOHO and Cluster to be selected as projects. (As we shall see, this impediment could be overcome thanks to the introduction of Cornerstone missions within Horizon 2000.)

Some of the scientists who had helped to formulate the ISTP programme at the preparatory meeting of September 1983 were asked to participate in a Joint Planning Group for ISTP, which then slowly built up the programme. As implied in the last but one paragraph, the origins of the ESA/NASA collaboration on SOHO and Cluster (the two missions that later became the first Cornerstone of Horizon 2000) can also be traced back to the Joint Planning Group.

SOHO as part of the first Cornerstone of Horizon 2000

The long term-programme that became known as 'Space Science: Horizon 2000' was a large community effort, guided and finally

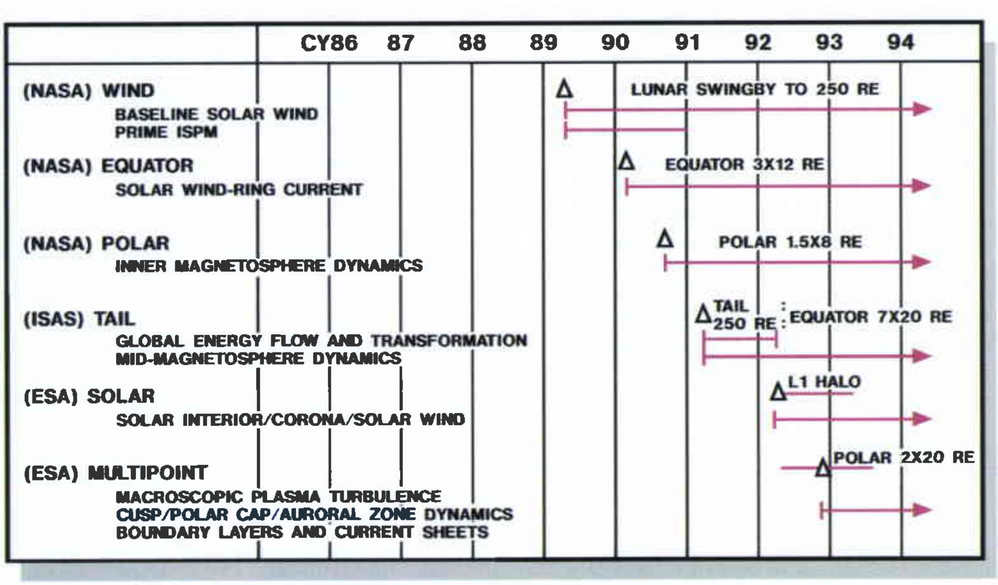


Figure 3. The original schedule for the International Solar-Terrestrial Science Programme, as elaborated at the trilateral ESA/NASA/ISAS Preparatory Meeting on Solar-Terrestrial Science, held in Washington DC on 26 and 27 September 1983. The two last missions, designated (ESA) 'Solar' and 'Multipoint', are the equivalent of SOHO and Cluster. Note that all of the missions shown on this figure from 1983 are now either flying, ready for launch (Cluster), or under development (Equator-S)

formulated by a Survey Committee composed of senior European space scientists, including all of the members of the ESA Space Science Advisory Committee. The procedure was started with a call to the wide scientific community for mission concepts, which were to form the basis for the Survey Committee's deliberations. After examining these mission concepts, Topical Teams drafted long-term plans for their respective disciplines.

The Topical Team for Solar and Heliospheric Physics concluded that 'a vigorous solar and heliospheric research programme commensurate with the capability, vitality and needs of the corresponding European community should be given strong support', and that 'the SOHO mission ... would provide major support for the International Solar-Terrestrial Physics Programme.'

The Space-Plasma Topical Team stated that 'of the missions under study, SOHO and Cluster (were) the ones of most interest to the plasma physicist'. They added: 'although each of them can stand on its own, much is to be gained if they are carried out as a European contribution to the International Solar-Terrestrial Physics Programme ...'.

At the final meeting of the Survey Committee in May 1984 in Venice, there were originally only three Cornerstones foreseen. These were what today are the XMM and the FIRST missions (covering X-ray and far-infrared astronomy), as well as a large, but not yet defined planetary mission. Given the European leadership in cometary research and the vigorous community who were working on meteorites and lunar samples, it was decided to define this third Cornerstone to be a 'Mission to Primitive Bodies including the Return of Pristine Materials'.

It was a surprise when a fourth Cornerstone, consisting of the SOHO and Cluster missions, and originally called the 'Solar-Terrestrial Physics (STP) Cornerstone', was introduced by M. Huber – then chairman of the Solar System Working Group – following a comment by CERN's L. van Hove regarding the bias toward astronomy (to the detriment of the solar-system sciences) that was inherent in the original plan with just three Cornerstones. It may well be that it was not immediately clear to all meeting participants what the STP Cornerstone was actually to be, in particular that it took up G. Haerendel's idea to combine SOHO and Cluster in one programme. In any case, the Executive returned next morning still with their original plan of three Cornerstones. This immediately attracted criticism from K. Fredga, B. Hultqvist (who had already given strong support to the idea of the STP Cornerstone the day before) and others. The ensuing discussions produced an admission of the feasibility of the STP proposal from the cost and schedule viewpoints and it was therefore reinstated. It quite naturally became the first Cornerstone, being renamed the 'Solar-Terrestrial Science Programme' (STSP) to make it a distinct element of the much larger ISTP Programme. The inclusion of this Cornerstone balanced the Horizon 2000 Programme between the disciplines represented by active researchers at the time.

Fitting SOHO (and Cluster) into a Cornerstone budget

Prior to the 1984 Survey Committee recommendation that SOHO and Cluster be combined to form the STSP Cornerstone, the two projects had been studied separately at both Assessment and Phase-A levels. In parallel, but within the framework of the Assessment Studies, discussions had taken place with NASA concerning a potential joint ESA/NASA/ISAS International Solar-Terrestrial Programme (ISTP) (see earlier). The Phase-A studies were conducted bearing in mind a potential ISTP collaboration between ESA and NASA.

Following the combination of the two projects as a Horizon 2000 Cornerstone, and when NASA's involvement became uncertain (for lack of a new start), further studies were conducted to investigate potential solutions for a purely European Solar-Terrestrial Physics Programme (ESTP). The conclusions were presented to the ESA Science Programme Committee (SPC) in February 1986. The SPC confirmed the choice of SOHO and Cluster as the first Cornerstone of Horizon 2000, but unfortunately the studies had resulted in an estimated cost of 555 Million Accounting Units (1984 economic conditions) for the European version and 562 MAU for the international option, not including the launch vehicle. In the worst-case scenario, therefore, where launchers would have to be purchased at full cost, the additional funds required could amount to approximately 200 MAU.

The main differences between the European and international options reflected a more comprehensive science payload and a potential STS (Shuttle) plus Upper Stage launch for the latter option. This placed additional technical/cost demands on the SOHO spacecraft and flight operations in particular.

In addition to these Phase-A results, an independent cost estimate, which included more recent developments in internal costs, was made and this amounted to some 590 MAU for the International STSP without the launch vehicles. It was this estimate that was taken as the technical and cost baseline.

The SPC wished, however, to impose the Cornerstone financial limit of 400 MAU (again at 1984 economic conditions) for the total ESA Science Programme contribution corresponding to either recommendation of the Survey Committee. Consequently, major cost surgery was needed and the SPC requested the Executive to vigorously pursue the financial goals set, without serious erosion of the science objectives. From now on, the cost of SOHO and Cluster was treated as a package.

The problem was to be approached from two directions. The first task was to involve the scientific community in a scientific and technical descoping exercise, with the intention of reducing the Cluster and SOHO spacecraft development and operations costs. The second task was to explore with NASA (the Phase-A partner) the possibility of increasing the international share in the missions and thereby reduce the overall cost to ESA.

In 1986 a scientific committee (Science Advisory Group, SAG) was set-up under the Chairmanship of D. Southwood to review and rationalise the scientific and technical requirements. In parallel, discussions were initiated with the NASA ISTP Project in pursuance of increasing the NASA share. Within both initiatives, a number of options were listed for technical and cost study.

Whilst the SAG was primarily focussed on scientific rationalisation of the mission, there was a degree of overlap with the activity concerning increased international participation. NASA had experienced financial problems in obtaining continued approval for their Equator mission, and wished to find a solution to this problem within the context of an arrangement for increased participation in STSP. Specifically, NASA requested that ESA explore the possibility of one of the four Cluster spacecraft performing an 'Equator mission' prior to joining the three remaining Cluster spacecraft and then completing the planned mission of STSP. This request was maintained under review by the SAG. Clearly, it had obvious technical/cost consequences originating from a combination of the two payloads and introducing a capability for Cluster to operate in two very different orbits over a longer period than the original Cluster requirement. As negotiations progressed, the desire to accommodate Equator requirements into the Cluster mission constituted the greatest risk in being able to reach an agreement on a package of increased NASA participation: the cost and technical risk to the Cluster mission became the primary ESA concern in seeking to accommodate the Equator requirements. Following extensive studies of the various options in both domains during 1987, by the end of the year promising proposals for reducing costs were emerging.

Major factors of scientific and technical rationalisation recommended by the SAG included:

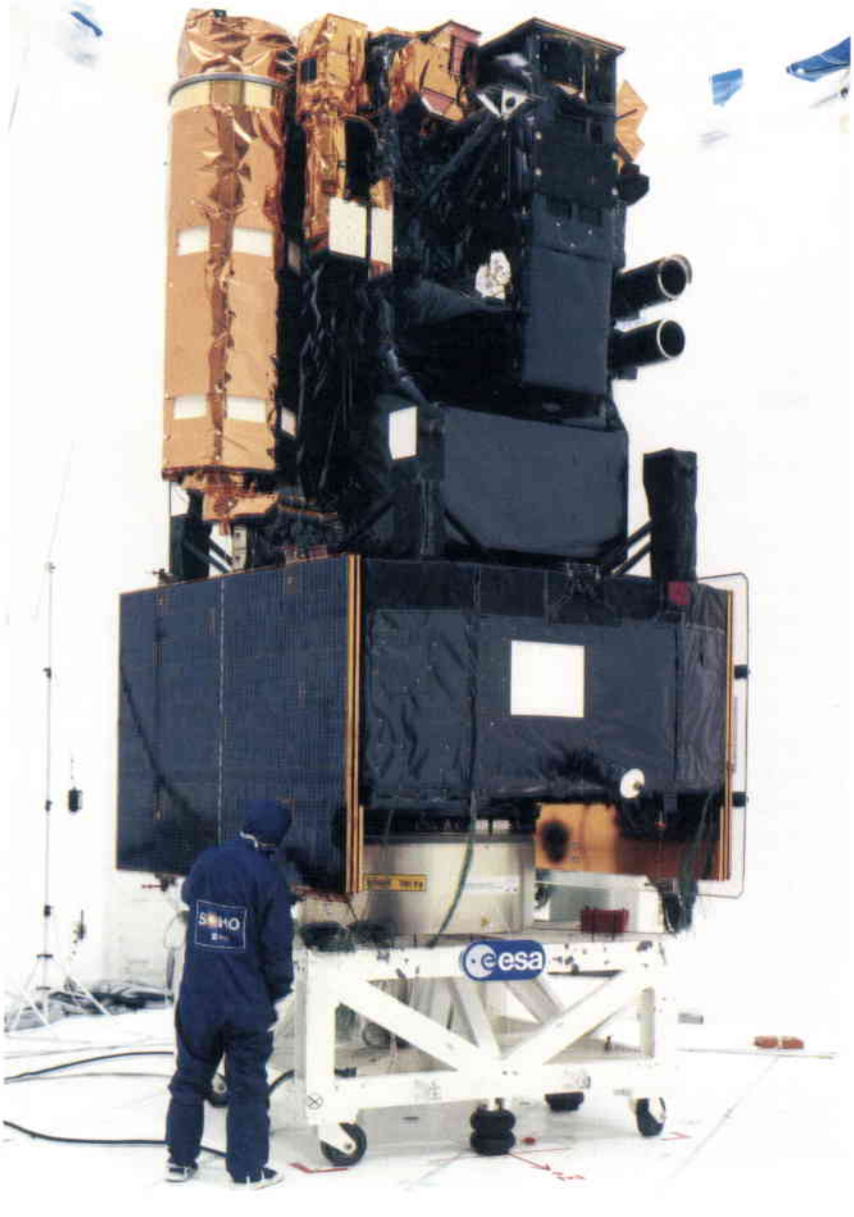
For Cluster:

- Agreement that all four Cluster spacecraft would be *identical, with identical science instrumentation*, such that development/qualification and documentation costs would only be experienced once in the programme.
- Cluster spacecraft would not provide inter-spacecraft stimuli and several experiments would be combined into a 'Wave Consortium'. Data-handling and control functions for the Wave Consortium would be provided by the scientific community.
- Long wire booms for the Wave Experiment would be experimenter-provided; traditionally these had been Agency-provided hardware.
- On-board memory of 1 Gbit would be provided on the spacecraft side, but the flight-operations scenario would be principally on a pre-planned basis without real-time operations.
- The Wide-Band Data Experiment would be confined to installation on two spacecraft and the reception of burst data from this experiment would be the responsibility of the Deep Space Network (DSN).
- ESA would not be required to fund a Science Operations Centre. The ESA responsibility for Data Dissemination would be limited to distribution of data on CD-ROM to Principal Investigators (PIs), with the technical potential also for PIs to dial into ESOC to obtain quick-look, short-history file data.
- The magnetic-cleanliness programme would be a joint effort between ESA and the PIs using the most cost-effective facilities and expertise wherever available.

For SOHO:
- Acceptance that pointing-stability and alignment requirements could be taken as a goal rather than as a specification.
- Acceptance that the technical requirements for magnetic characteristics as well as surface conductivity could be taken as design goals.

Concerning the dialogue with NASA, progress was made along several avenues, including:
- Provision by NASA of the SOHO launch using an Expendable Launch Vehicle (ELV).
- Agreement by NASA to transfer the implementation of the SOHO flight operations from ESOC to NASA/GSFC, including use of the DSN for data retrieval.
- Provision by NASA of several spacecraft hardware items such as tape recorders, high-power amplifiers for both SOHO and Cluster, and the provision of fine Sun sensors for SOHO.

Figure 4. The SOHO spacecraft in launch configuration



- Provision by NASA of flight-model environmental test facilities for SOHO, an option subsequently not taken up by ESA.

Unfortunately at the time, the request concerning Equator was becoming a major block to reaching agreement. It became evident, however, through the multiple interactions, studies and reviews, that the risk to Cluster was not in the interests of either party, and consequently NASA reluctantly agreed to drop the request.

Clearly, even though major savings to ESA were becoming viable, the full launch cost for Cluster was still a problem. The mission needed a full Ariane-4, resulting in some 100 MAU of additional cost which simply could not be met. Following extensive representation with the Ariane Programme, agreement was finally reached that Cluster could be launched as an APEX passenger on one of the Ariane-5 qualification flights, at a cost of about 13 MAU to cover APEX charges.

By November 1987, the complete package of science descoping/rationalisation, expanded international cooperation, together with the APEX opportunity for Cluster, offered a real opportunity for cost reductions within STSP, resulting in an estimated cost to ESA of 500 MAU, including launch vehicles: a saving of some 250 MAU! However, the problem still remained of how to meet the SPC limit of 400 MAU.

In dialogue with the SPC, it had been concluded that for the particular case of STSP, a special Cornerstone target revision from the canonical 400 MAU to 460 MAU (1984 economic conditions) could be permitted, but further actions had to be undertaken to identify further reductions below the 500 MAU estimate. In the meantime, the Payload Announcement of Opportunity could be released.

It was decided that the best approach for studying further cost reductions would be a joint effort by the ESA project and the scientific community, represented by a small committee under the chairmanship of H. Balsiger.

A very detailed and careful joint review of all project costs and cost-estimating history was conducted, and several economies were introduced into the project team (manpower, other ESA facility and manpower costs, together with estimates for the industrial elements). This resulted by end-1987/early-1988 in a total STSP estimate of 484 MAU (1984 economic conditions), compared with the SPC's revised limit of 460 MAU.

Whilst this estimate did not fully match the desired limit, it was felt that sufficient confidence now existed in both the technical and cost project baselines that STSP should go ahead and that the estimates should be further revised at the end of Phase-B, when the real industrial costs would be known.

During the process of pre-Phase B and Phase-B itself, some of the agreements concerning both scientific rationalisation and international cooperation were modified, but in introducing these into the Phase-B, working in close co-operation with Industry, the final cost estimate presented to the SPC amounted to 474 MAU, a figure that it found acceptable. Both the Cluster and SOHO projects effectively completed their Phase-B in the spring of 1991 with viable solutions from the standpoints of science, full mission technical integrity and cost. The continuous pressure on cost initiated in 1986 had resulted in a mission saving to ESA of approximately 275 MAU and had provided a practical implementation opportunity for the first Cornerstone of Horizon 2000.

The SOHO payload and its development

There were three remarkable aspects to SOHO's payload selection. The first concerned the decision of the Director of Science to remove the plasma payload, including (to the great dismay of the USA's N. Ness and Germany's H. Rosenbauer) the magnetometer. This saved considerable cost by avoiding a magnetic-cleanliness programme – quite a dramatic issue given the numerous mechanisms in the large optical instruments.

The second major event in the selection process was the re-institution by the Solar System Working Group of the proposed Ultraviolet Coronograph Spectrometer (UVCS). The peer review committee recommended flying a visible-light coronograph (LASCO) only, since both UVCS and LASCO had been proposed by American PIs and flying both of these instruments was claimed to be placing too much of a strain on NASA's resources. However, the novelty of the UVCS measurements and the substantial Italian participation in and contribution to the UVCS instrument eventually led to its reinstatement into the payload.

The third issue concerned the Extreme-ultraviolet Imaging Telescope (EIT), which was preferred over the X-ray Telescope (XT). While the latter design featured a telescope imaging the entire solar disc and lower corona using the more conventional grazing-incidence optics, EIT was to be a rather novel design of normal-incidence optics with selectively reflecting thin-layer coatings peaked around four prominent solar lines in the EUV, a design never before flown on a satellite. Eventually, the better image definition at the solar limb afforded by the EIT was the reason for preferring the more novel design, although it obviously carried greater risk.

A rather dramatic decision had to be taken when it turned out that the industrial contractor building the imaging detectors for two of the instruments – SUMER and UVCS – was not capable of meeting its technical commitments within schedule (already during the GRIST study it was proposed that ESA's Technology Research Programme should pursue the development of European UV imaging detectors suitable for the count rates associated with solar observations, but no such effort materialised). Barely one and a half years before launch, it was decided to replace the original design with so-called 'XDL-detectors'. They were built in a University of California (Berkeley) laboratory, without formal product assurance in order to meet the schedule and to stay within the budgetary constraints.

Conclusions

The very involved and eventful history of SOHO has led to a payload and overall mission design are state of the art in terms of solar space observations and the latest developments in solar physics, especially as regards the new discipline of helioseismology. The data now coming in from the ensemble of observing instruments on-board SOHO are redeeming the careful planning and fully justifying the considerable effort and finance invested in the realisation of this important mission.

The enthusiastic international atmosphere prevailing at the Experiment Operations Facility (EOF), where the investigator teams plan the joint observing programme and receive and evaluate the quick-look data, are a magnificent testimony to the power of science to transcend national and discipline boundaries and establish its own international and multi-disciplinary culture!

An article devoted to the early scientific results from SOHO will appear in the next issue of ESA Bulletin.

The ESA Ulysses Data Archive

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On 30 September 1995, Ulysses completed its prime mission to explore the high-latitude regions of the heliosphere, becoming the first spacecraft to truly escape from the confines of the ecliptic plane. The spacecraft's scientific payload has returned unique and continuous data throughout, covering the in-ecliptic transfer orbit to Jupiter, the flyby of the giant planet, the descent to the south pole of the Sun, and the subsequent ascent over its north pole. With approval from the funding agencies to extend the mission for a second solar orbit, the complete set of Ulysses measurements will provide an invaluable source of data for space scientists, as well as being of interest to the wider scientific community.

The ESA archive for Ulysses data provides public access to the measurements made by the spacecraft, together with the documentation needed for their correct interpretation. Plots of selected parameters have been generated and are available on-line for viewing or downloading. The archive, which takes advantage of the infrastructure of the Internet made available through the World Wide Web, will become the central repository in Europe for measurements made throughout the mission's lifetime.

Introduction

The joint ESA/NASA Ulysses mission, launched on 6 October 1990 to explore the heliosphere at high latitudes for the first time, recently completed its prime mission (Fig. 1) and has now embarked on a second solar orbit. The spacecraft has provided continuous scientific measurements during its in-ecliptic transfer to the Jovian system (see ESA Bulletin No. 67), its flyby of the giant planet (see ESA Bulletin No. 72), its descent to the south solar pole (see ESA Bulletin No. 82), and its ascent over the north solar pole.

After a proprietary period during which the Ulysses investigators have exclusive rights to analyse and publish their observations, the data enter into the public domain. The ESA archive for Ulysses data provides public access to measurements made during the mission and the documentation needed for

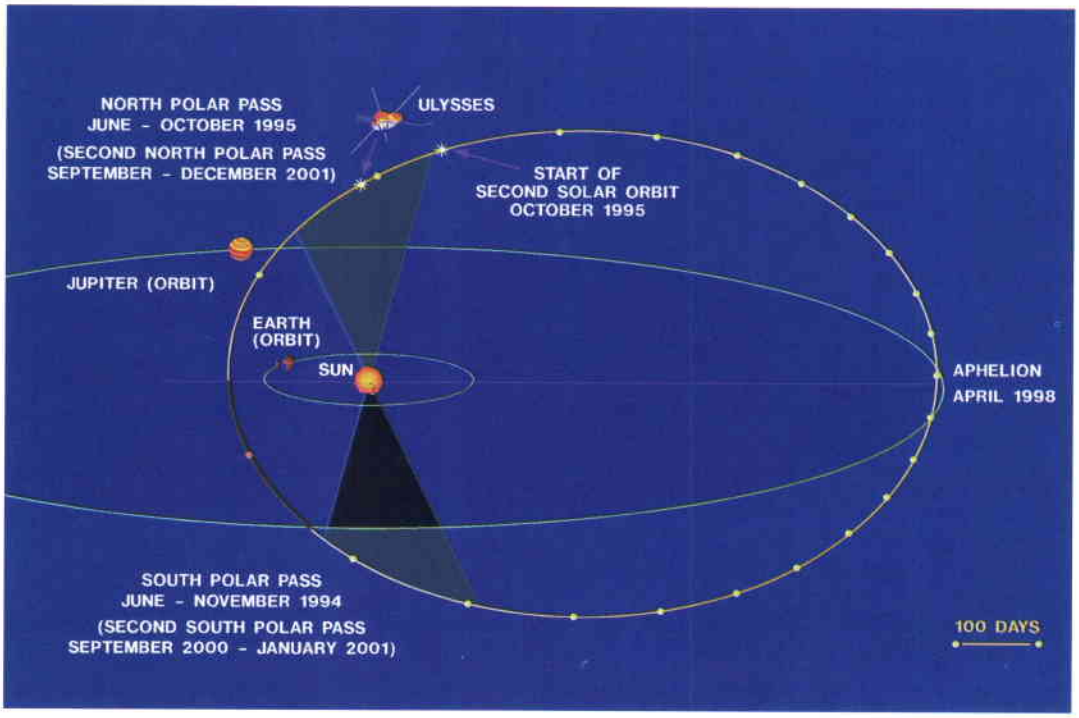


Figure 1. The Ulysses trajectory for the prime mission

* Currently assigned to the Mathematics and Software Division, ESTEC, Noordwijk, The Netherlands

their correct use. It will also be established as the permanent archive in Europe for all Ulysses data. These activities are performed in the United States by the National Space Science Data Center (NSSDC) and (for the subset of data taken at Jupiter) by the Planetary Data System (PDS), and are coordinated with ESA activities where appropriate.

Unlike NASA, ESA did not explicitly include archiving activities in the Ulysses mission plan, and work in this area only commenced in mid-1993, following approval by the Agency's Science Programme Committee.

Initially, data were defined and generated for the Ulysses Data System (UDS) which provided Ulysses investigators with access to measurements from all instruments within the framework of a computer network restricted to the Ulysses science community. The primary intention of the UDS was to encourage correlative studies between the Ulysses teams by facilitating the exchange of data. Having established the UDS, the data sets were used to form the basis of a public archive, at first by NSSDC, and more recently by ESA.

The ESA archive makes full use of the infrastructure of the Internet provided through the increasingly popular World Wide Web (WWW), taking advantage of the HyperText Markup Language (HTML) for designing graphical user interfaces, the File Transfer Protocol (FTP) for file transfer, and software to browse the contents of web sites (such as Mosaic and Netscape, or Lynx for platforms not supporting graphics and windows applications).

This article describes in detail the data sets held on-line by the ESA archive and the information necessary to access them. Additional applications, such as a simple plotting package to view the data, and a search of a database storing an up-to-date list of references to scientific papers written using Ulysses data, are also reported.

The data sets

The scientific payload of Ulysses comprises (Fig. 2):
– two magnetometers (VHM/FGM) to provide high-resolution measurements of the interplanetary magnetic field
– a solar-wind plasma instrument (SWOOPS) to derive the bulk properties of the solar wind

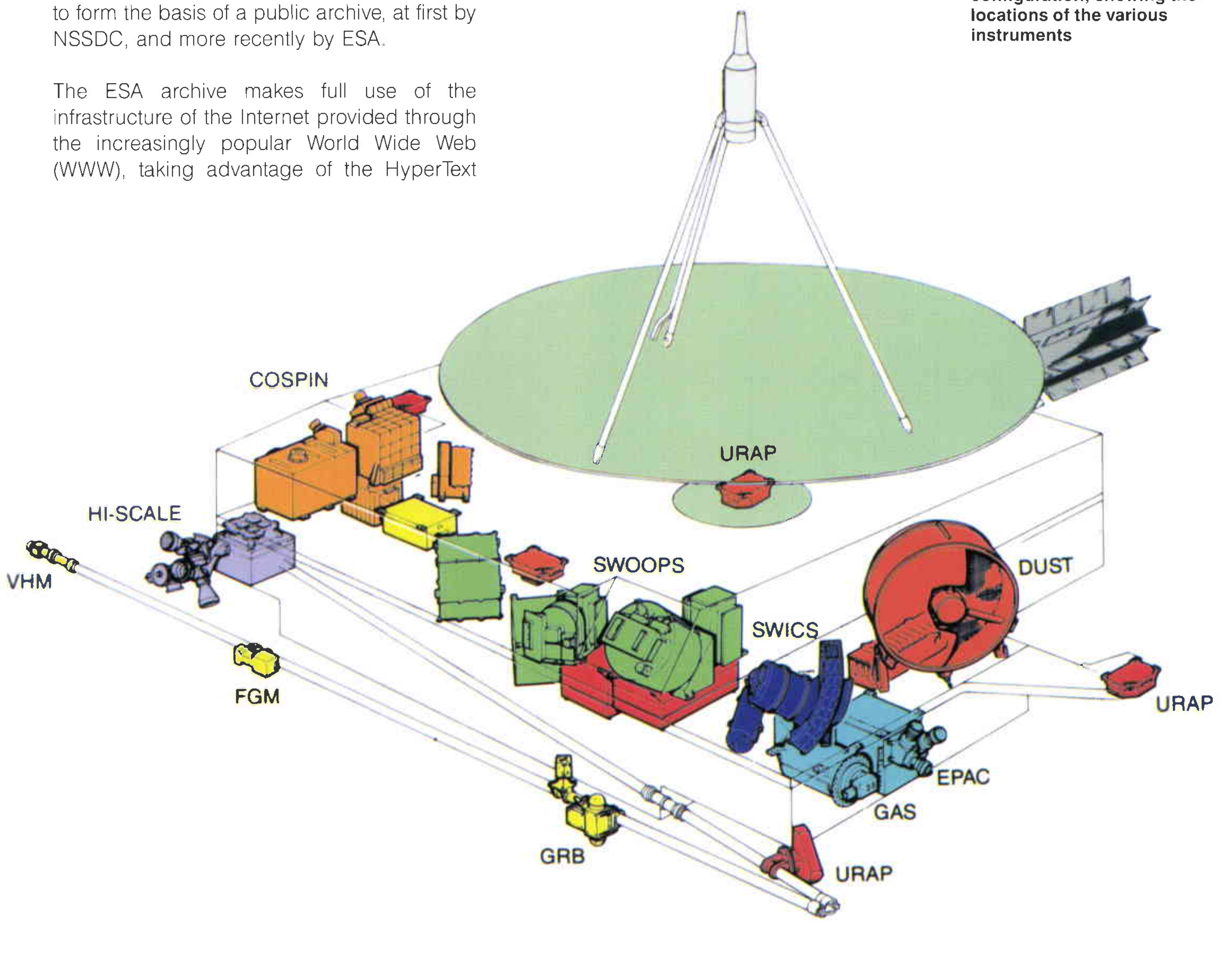


Figure 2. The Ulysses spacecraft in launch configuration, showing the locations of the various instruments

- a solar-wind ion-composition experiment (SWICS)
- three sets of charged-particle detectors (EPAC, HI-SCALE and COSPIN) to quantify ion and electron fluxes over a wide range of energies and for many ion species
- a combined radio- and plasma-wave instrument (URAP)
- a solar X-ray and ϒ-ray detector (GRB)
- a cosmic dust experiment (DUST), and
- an interstellar neutral-gas instrument (GAS).

Radio-science experiments have also been performed (SCE and GWE) making use of the spacecraft's radio communication link in specific periods.

Each experiment team is led by a Principal Investigator (PI), and involves Co-Investigators (Co-I's) from European and American institutes (Table 1). In total, more than 120 scientists are directly associated with one or more of the investigations.

The data sets used for the archive have been generated by the PI teams, thereby guaranteeing the use of the best data-reduction algorithms available. The selected time resolution of the data sets is not necessarily the highest resolution of the experiment. Instead, a compromise is often necessary in order to ensure the statistical validity of the measurement without restricting the scientific potential of the data. Furthermore, the physical

Table 1. The Ulysses scientific investigations

Investigation	Acronym	Principal Investigator	Measurement
Magnetic field	VHM/FGM	A. Balogh, Imperial College, London (UK)	Spatial and temporal variations of the heliospheric magnetic field: 0.01 to 44000 nT
Solar wind	SWOOPS	J.L. Phillips, Los Alamos National Lab. (USA)	Solar-wind ions: 260 eV/q to 35 keV/q; Solar-wind electrons: 0.8 to 860 eV
Solar-wind ion composition	SWICS	J. Geiss, Univ. of Bern (CH) G. Gloeckler, Univ. of Maryland (USA)	Elemental and ionic-charge composition, temperature and mean speed of solar-wind ions: 145 km/s (H^+) to 1350 km/s (Fe^{+8})
Radio and plasma waves	URAP	R.J. MacDowall, NASA/GSFC (USA)	Plasma waves, solar radio bursts, electron density, electric field Plasma waves: 0 – 60 kHz; radio: 1 – 940 kHz; magnetic: 10 – 500 Hz
Energetic particles and interstellar neutral gas	EPAC/GAS	E. Keppler, MPAe, Lindau (D)	Energetic ion composition: 80 keV – 15 MeV/n Neutral helium atoms
Low-energy ions and electrons	HI-SCALE	L.J. Lanzerotti, AT&T Bell Labs., New Jersey (USA)	Energetic ions; 50 keV – 5 MeV Energetic electrons: 30 – 300 keV
Cosmic rays and solar particles	COSPIN	J.A. Simpson, Univ. of Chicago (USA)	Cosmic rays and energetic particles Ions: 0.3 – 600 MeV/n Electrons: 4 – 2000 MeV
Solar X-rays and cosmic gamma-ray bursts	GRB	K. Hurley, UC Berkeley (USA) M. Sommer, MPE, Garching (D)	Solar-flare X-rays and cosmic gamma-ray bursts: 15 – 150 keV
Cosmic dust	DUST	E. Grün, MPK, Heidelberg (D)	Dust particles: 10^{-16} to 10^{-7} g
Coronal sounding	SCE	M.K. Bird, Univ. of Bonn (D)	Density, velocity and turbulence spectra in the solar corona and solar wind
Gravitational waves	GWE	B. Bertotti, Univ. of Pavia (I)	Doppler shifts in spacecraft radio signal due to gravitational waves

parameters included in the data files do not always represent an exhaustive list of measured quantities. This may apply to measurements contaminated by noise, or may simply be to limit the size of the data files.

The organisation and formatting of the files is kept as uniform as possible, the general case being one ASCII file per day for each experiment (or subsystem of an experiment). However, there exist a few exceptions to this guideline, most notably the GRB data set, which because of its high time resolution is stored in binary format and then further compressed in order to conserve both disk space and data transmission times.

Table 2 summarises the current data sets available on-line from the ESA archive, providing information about the time resolution of the data and the physical parameters included in each file. From the typical size of each file, estimates are provided of the total disk storage required for each experiment for the prime mission. As higher resolution data become available to the archive, these figures will increase, necessitating the use of alternative storage media such as CD-ROMs.

Access to the public archive
Access to the ESA archive for Ulysses data can be gained through the WWW. Using a browser, such as Mosaic or Netscape, it is necessary to open a Universal Resource Locator (URL) pointing to

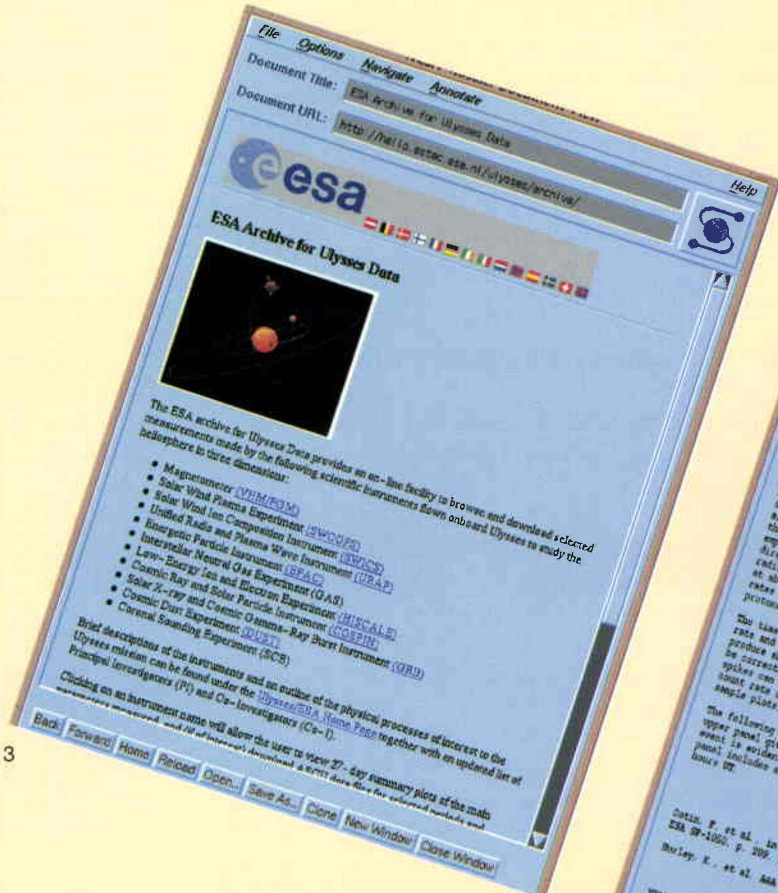
http::/helio.estec.esa.nl/ulysses/archive/

to reach the top-level page of the archive directory. Figure 3 shows the layout of this home page, as seen with the Mosaic browser.

Detailed information about how to contact the PI and the investigation representative responsible for generating the data sets is provided for each experiment. Indeed, any user wishing to use Ulysses data for scientific analysis is requested to contact the relevant PI to inform him of their intention, and is recommended to collaborate with the experiment team where appropriate.

Table 2. The data set currently available from the ESA archive for Ulysses data

Instrument	Measured Parameters	Data Available	Time Resolution	Estimated Volume of Prime Mission Data (MByte)
VHM/FGM	Magnetic field (Total field and components)	298/90 – 273/93	1 hour	3
SWOOPS/IONS/ELECTRONS	Ion velocity, temperature and density Electron velocity, temperature and density	322/90 – 365/94 322/90 – 366/92	4 minutes and 1 hour 4 minutes	45 40
SWICS	Velocity, temperature and density for selected ion species	341/90 – 365/93	3.5 hours	2
URAP	Peak and average electromagnetic wave intensities	307/90 – 365/94	10 minutes	400
EPAC	Ion and electron fluxes	274/90 – 365/94	1 hour	140
HI-SCALE	Ion and electron fluxes	318/90 – 365/94	1 hour	30
COSPIN/AT	Ion fluxes	001/91 – 365/93	10 minutes	50
COSPIN/LET	Ion and electron fluxes	296/90 – 365/94	10 minutes	80
COSPIN/HET	Ion and electron fluxes	296/90 – 365/94	10 minutes	40
COSPIN/HFT	Ion and electron fluxes	296/90-243/94	10 minutes	40
COSPIN/KET	Ion and electron fluxes	296/90 – 365/94	10 minutes	70
GRB	Detector count rates	302/90 – 365/94	0.25 – 2 seconds	3000
DUST	Dust impact speed, mass and arrival direction	launch – end 1992	N/A	N/A



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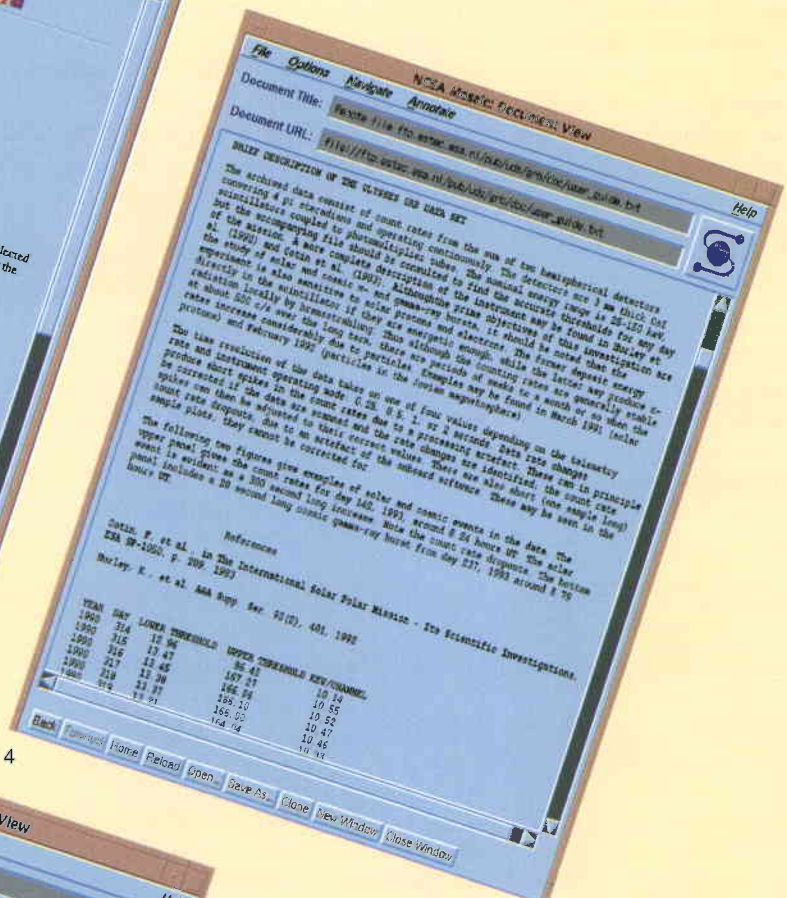

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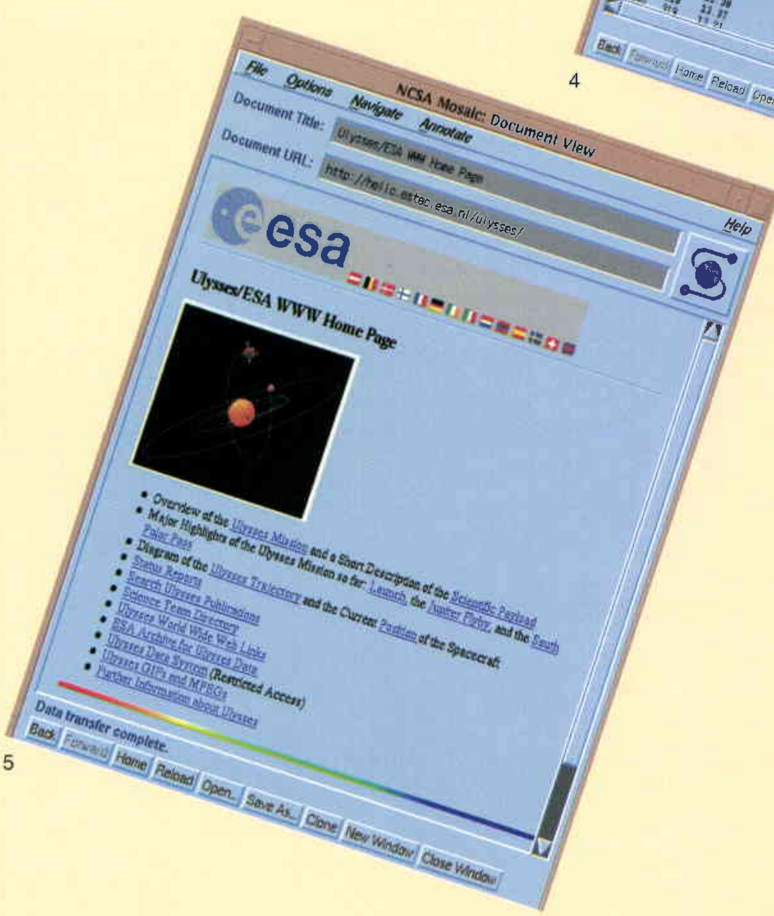

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Figure 3. The archive's WWW home page, as viewed using the Mosaic browser

Figure 4. The data-set description for the GRB experiment

Figure 5. The Ulysses/ESA home page, as viewed with Mosaic

Also available is a short description of the data products supported by the archive, which include previously generated 27-day (approximately corresponding to the synodic rotation period of the Sun) PostScript plots for browsing periods of interest, data files (compressed and grouped into yearly files), and documentation material (including format descriptors to read the data files, detailed information about the instrument, caveats and data reduction techniques used, and a list of relevant references). As an example, Figure 4 shows the data-set description for the GRB instrument. More general information about the Ulysses mission itself, including regular status reports and the current spacecraft position, can be found on the accompanying Ulysses/ESA page using the URL

http::/helio.estec.esa.nl/ulysses/

This page also provides links to the Web sites maintained by the Ulysses institutes, the NASA Ulysses page at Jet Propulsion Laboratory (JPL), and the US archive sites at NSSDC and PDS.

The layout of this page is shown in Figure 5, again using the WWW browser Mosaic.

Measurements made by the solar-wind plasma instrument (SWOOPS) and the Low-Energy Telescope of the COSPIN particle instrument, from launch until the end of 1994, are shown in Figures 6 and 7, respectively, as examples of the quality of data available from the public archive.

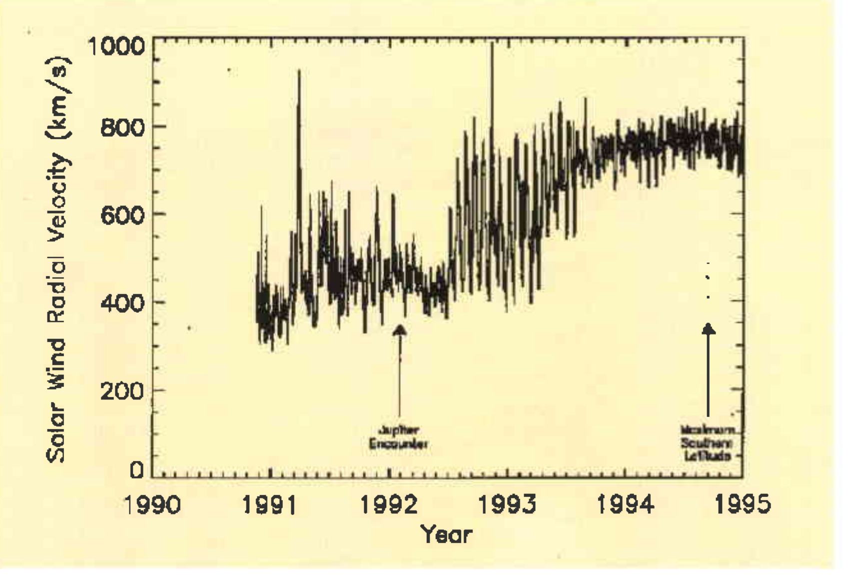

Figure 6. Solar-wind velocity measured by the SWOOPS instrument from launch until the end of 1994 (Courtesy of J.L. Phillips, Los Alamos National Laboratory)

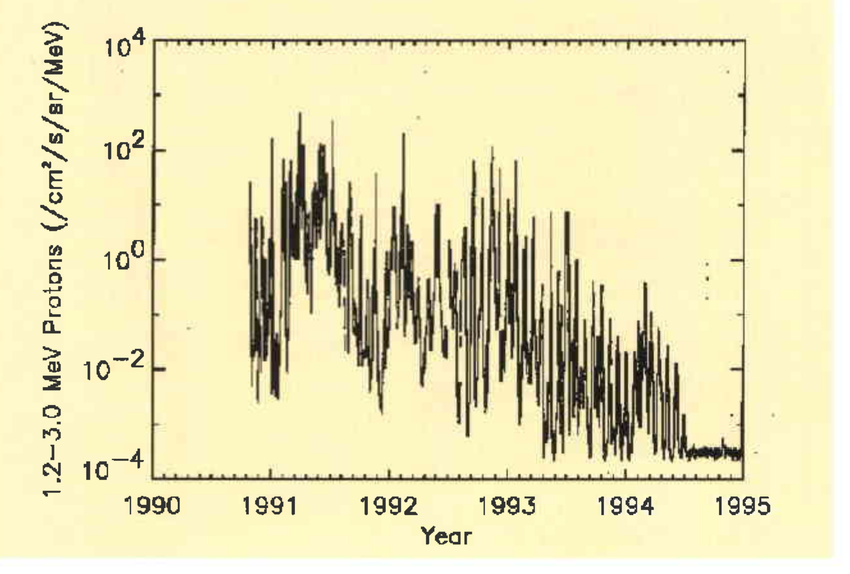

Figure 7. Proton intensities in the L2 (1.2 – 3.0 MeV) channel of the Low-Energy Telescope of the COSPIN instrument

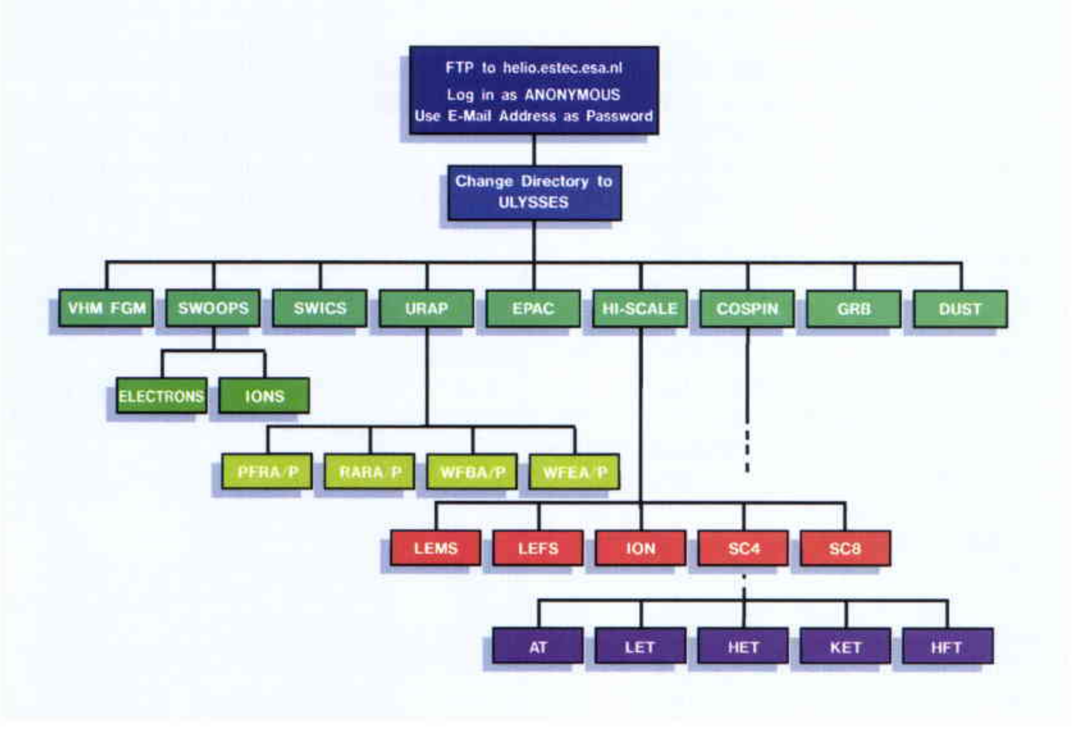

Figure 8. Summary of FTP access procedures and the Ulysses data archive directory structure

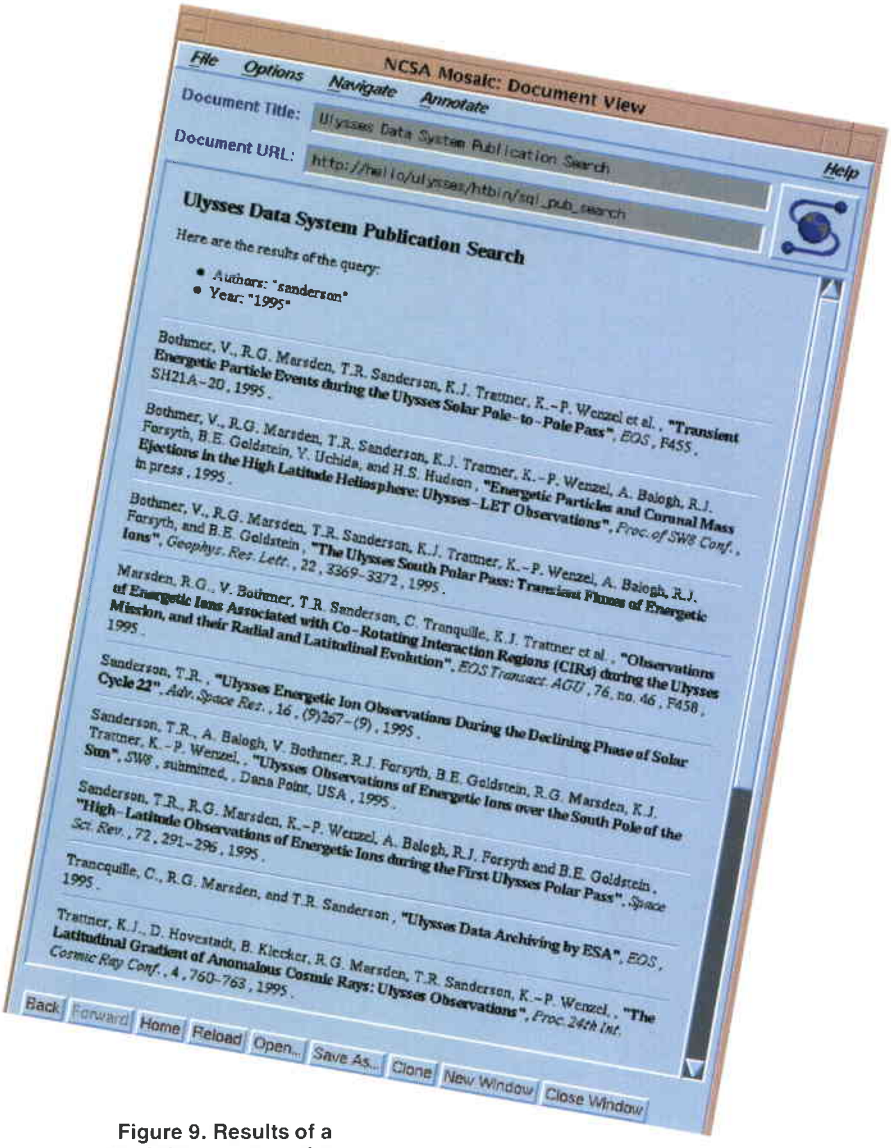

Figure 9. Results of a real-time query to the Ulysses publications database

The archive data and data products are stored on an anonymous FTP server, which is a dedicated computing facility belonging to the ESA Space Science Department at ESTEC for staging information and data for public access. It is therefore possible to obtain Ulysses archive products directly by using anonymous FTP to the server **helio.estec.esa.nl** (or using the IP number 131.176.17.136) and logging in with ANONYMOUS as the user name and providing the user e-mail address as the password. The Ulysses data products are located in the 'ulysses' directory and are arranged in sub-directories named according to the experiment and the type of product. Figure 8 summarises the FTP access procedures and portrays the directory structure.

Ulysses trajectory information is also available through the Ulysses archive. Daily values for the spacecraft's position in heliocentric and geocentric coordinates are provided for the prime mission and for the second solar orbit. This information was supplied by the Ulysses project office at JPL.

The software used to generate the 27-day plots will shortly be interfaced to the archive home page, to allow users to make 'on-the-fly' plots of selected parameters and time intervals.

A useful application offered by the Ulysses/ ESA home page is a facility allowing a dynamic search of a database (maintained by the Ulysses science team at ESTEC) containing references to papers published in scientific journals using Ulysses data. This search uses the standard SQL interface to query a relational database (RDB) in real time, and is interfaced to the WWW page using HTML forms. The search capability allows multiple selection of authors, character strings contained within the article title, journal and year of publication. An example of the result of such a search is shown in Figure 9. In the future, this facility will be extended to provide the user with the text of the article's abstract.

Future developments

The ESA archive for Ulysses data will continue to add new data as they come into the public domain. The data sets will also be updated if a more complete selection of parameters becomes available, or if more refined data-reduction algorithms are employed to generate them. It is planned to make higher resolution data available when submitted to the archive by the experiment teams. Such voluminous data sets will most likely be stored off-line, and will need to be requested by interested users and distributed on high-density media such as DATs or exabyte tapes and CD-ROMs. Available non-electronic data products, such as microfiche plots (as supplied by the investigator teams) and data books, will be announced and mailed upon request.

In summary, the ESA data archive will allow today's space scientists easy access to the measurements made during the Ulysses mission, but will also ensure the data's availability for future generations.

Transfer of ESIS to Scientific Institutes

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The European Space Information System (ESIS) is a tool that allows the space science community to access catalogued and archived data from geographically distributed archive sites. The system had been based at ESRIN, ESA's establishment in Italy since its inception, but its various components were transferred to several European astronomical institutes in December 1995. They are now being implemented within the institutes' existing archive environments and will provide a basic access infrastructure to future archives.

In the year leading up to the transfer, the system was adapted to support the institutes' environments. In order to fulfil all requirements and to establish a tool in which the scientific community can cooperate and access several archive sites, a multi-server/multi-client architecture, based on the World Wide Web, was adopted.

Introduction

The European Space Information System (ESIS) provides 'homogeneous access to heterogeneously and geographically distributed data archives' in the astronomical and space physics domains. It was initiated in 1987 as a pilot project to support the space science community, but has evolved over the years to adapt to the changing needs and requirements of the community.

It allows a uniform access, retrieval, visualisation and manipulation of archived data. The main tools of the system are based on a Catalogue Browser, an Imaging package, a Spectral package and a Timing package. With the help of the SIMBAD database, located at the Centre de Données astronomiques de Strasbourg in France, used as a celestial name and coordinates resolver, ESIS was the first astronomical system to provide this resolver feature to the astronomical community to allow the user to access multiple astronomical catalogues.

ESIS, however, had to be transferred to several European astronomical institutes that had expressed interest in obtaining one of the components. The system therefore had to be adapted to support the different environments that the various institutes operate. Prior to the final transfer in December 1995, all ESIS applications were ported to support access to data through the World Wide Web. Not only was the Catalogue Browser with its form-based interface adapted to World Wide Web browsers, such as Netscape and NCSA Mosaic, but all ESIS applications now act as World Wide Web clients to access the various archived data worldwide.

ESIS has two components: the astronomical ESIS and the space physics ESIS. The astronomical system is discussed here. The space physics system transferred to the scientific institutes is similar in concept.

Organisation of astronomical observations

Data from astronomical observations are basically organised in two different ways: databases containing catalogues, and archives containing data sets (Fig. 1). The catalogues and data archives are distributed worldwide.

A catalogue database consists of tables representing astronomical catalogues and mission logs. An astronomical catalogue is a table of astronomical objects and associated measurements. The measurements are expressed in a variety of physical units, depending on the wavelength region in which they are observed. A mission log is a list of astronomical observations for a single mission or instrument. Entries in mission logs refer, most often, to one or more data sets for a particular mission, located in different data archives.

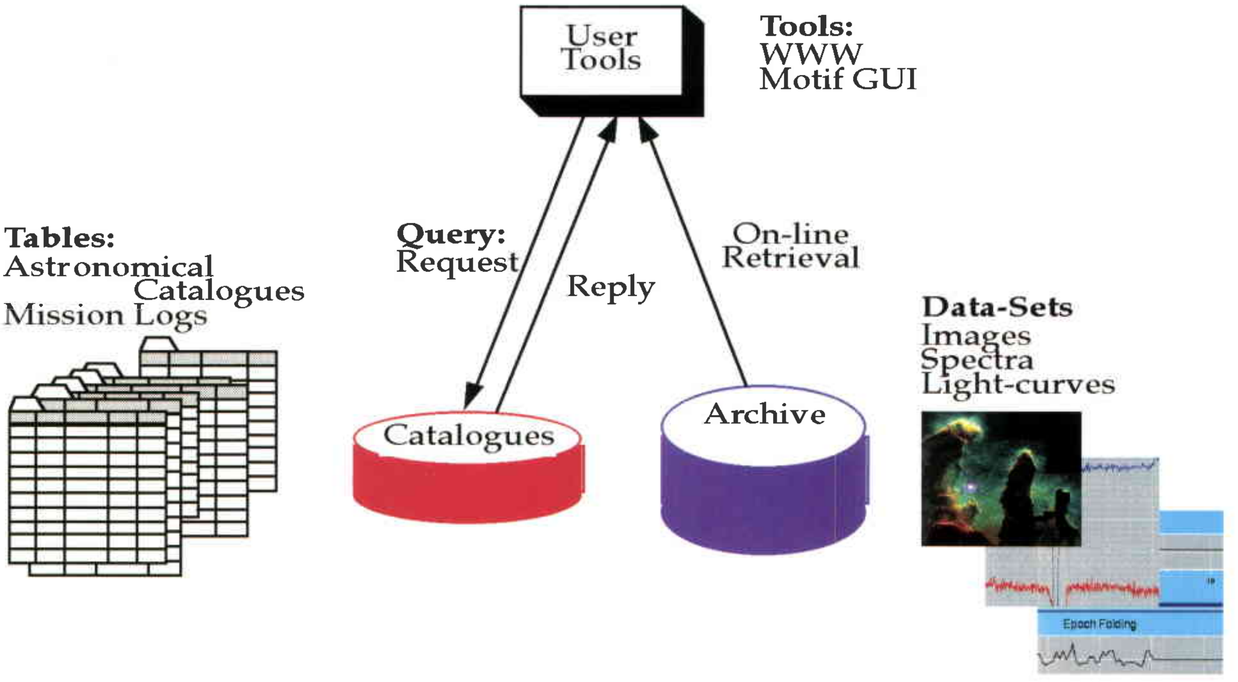

Figure 1. Organisation of astronomical data. User tools must be able to access astronomical catalogues and archives of astronomical datasets

The principal categories of astronomical datasets are images, spectra and light-curves.

Purpose of ESIS

ESIS has three main functions:

— To provide a search facility, which can be used to search multiple databases of astronomical catalogues, with the data-bases being geographically distributed and heterogeneous.
— To provide a facility for on-line retrieval of astronomical datasets, integrated with the search facility.
— To provide a set of astronomical data visualisation and manipulation packages, integrated with the search and data retrieval facilities.

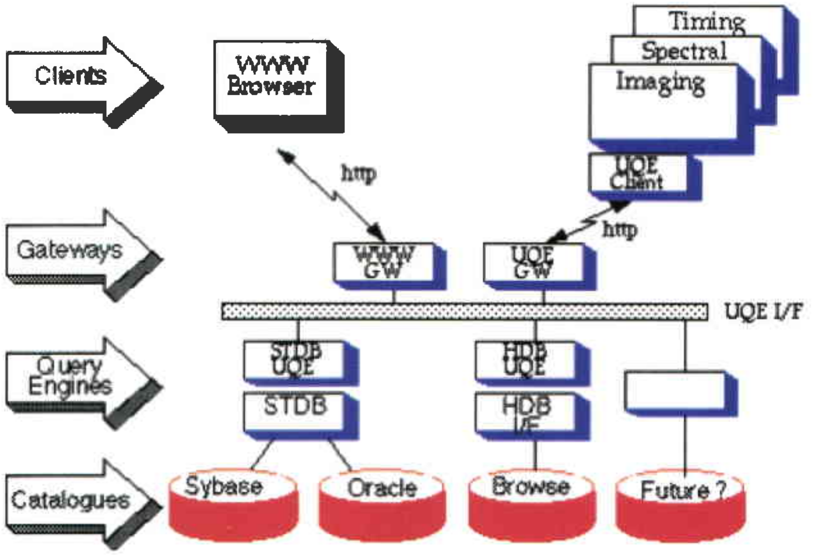

Figure 2. Overview of the ESIS architecture, showing the interactions between software components. An intermediate interface layer, the Uniform Query Engine (UQE), was introduced to allow interoperability between clients and catalogue servers.

The multi-client/multi-server problem

A problem arose, however, with the transfer of the components to the institutes because the different sites have different Database Management Systems (DBMSs), rendering access to the astronomical catalogues and archived datasets incoherent.

Some sites use the Sybase Database System, while others use Oracle, and NASA/HEASARC has developed its own database system called Browse. In order to provide transparent access to the DBMSs and catalogue interoperability, catalogue servers must — independently of their specific DBMS — appear the same towards the clients. The interoperability between catalogue servers has been achieved through the introduction of an intermediate interface layer, referred to as the Uniform Query Engine (UQE), based on two principles:

1. A clear definition of all necessary interactions required by the system to support the basic access and retrieval functions (Fig. 2). This is achieved by implementing DBMS-specific query engines. In the case of Sybase and Oracle, the uniform layer is based on the Space Telescope Database (STDB) library. In the case of Browse, the HEASARC Database (HDB) library is used.

2. A Reference Directory containing all the necessary meta data, describing catalogues and their physical parameters, to uniformly access a remote site.

Astronomical datasets are made available from archives by means of three different protocols: File Transfer Protocol (FTP), Hypertext Transport Protocol (HTTP), and client/server-specific tools based on the native DBMS. For example, to de-archive preview HST data, a client/server provided by the Canadian Astronomical Data Centre had to be integrated with ESIS applications.

The Catalogue Browser

The ESIS WWW Catalogue Browser (WCB) allows direct access to astronomical catalogues at any archive site supporting a WWW server with ESIS gateway scripts (Fig. 3).

This component of ESIS has been transferred to the Centre de Données astronomiques de Strasbourg (CDS) in France and is now provided as the 'VizieR service'. Being the astronomical data hub for the world, the CDS provides astronomical catalogues and an increasingly large amount of published tables of the *Astronomy and Astrophysics* journal. As part of the CDS overall services, the VizieR Catalogue Browser plays a major role in allowing the scientific community to search, browse and retrieve catalogued entries. There are currently almost 800 catalogues in the VizieR service.

ESIS applications

The ESIS visualisation and manipulation packages are Graphical User Interfaces that allow the search and retrieval of datasets from any remote archive site running a World Wide Web server. All three types of datasets are supported: images, spectra, and light curves.

Based on the Xanadu library, which was originally developed by the Exosat mission scientific team, each package contains its own search facilities to browse through multi-wavelength data using the standard search paradigms provided for catalogue browsing: by coordinate or by parameter.

Once a dataset is identified, it is de-archived and downloaded to the user's platform.

All searches in ESIS applications are done transparently, without the user having to first identify the location of an archive site. The applications are supplied with a configuration file that allows users to declare all archive sites running a World Wide Web server with the set of ESIS-specific access scripts (Figure 4 shows an example of a spectral application).

The ESIS applications are now being transferred to four institutes: the European Southern Observatory in Germany; the SAX mission group at the Italian Space Agency; the

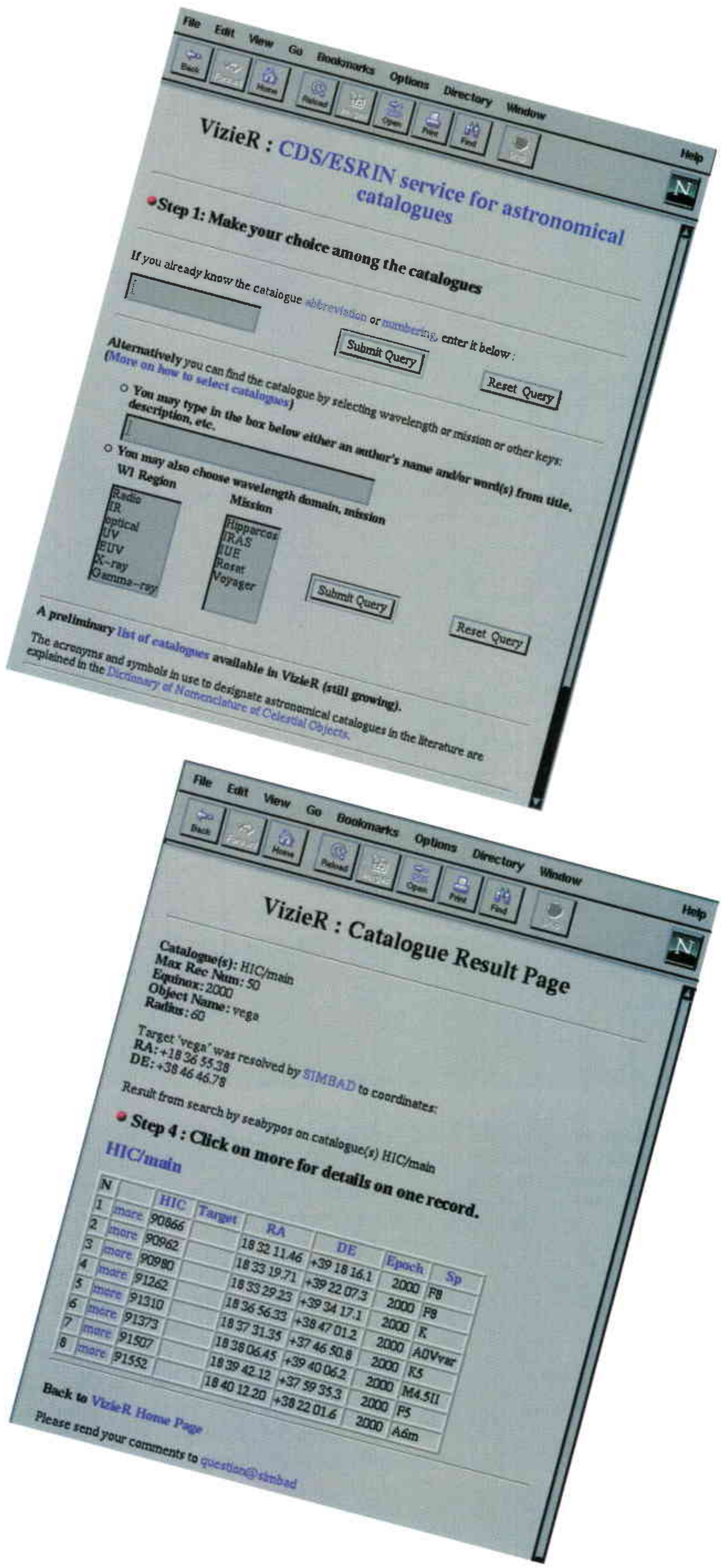

Figure 3. Examples of the WWW Catalogue Browser accessible from the CDS. On the top, the first screen from which a user selects catalogues to make subsequent searches. On the bottom, a typical result from the Hipparcos Input Catalogue.

Brera Observatory in Italy; and the Monte Porzio Observatory, also in Italy.

Conclusions

The latest version of ESIS (Version 4), which was transferred to the scientific institutes, has provided a solution to the problem of transparent access to multiple and heterogeneous catalogues located on distributed query servers under different DBMSs. The feasibility of the adopted concepts and the implemented solution has been confirmed during the operational phase of the CDS/VizieR catalogue service throughout the last few months.

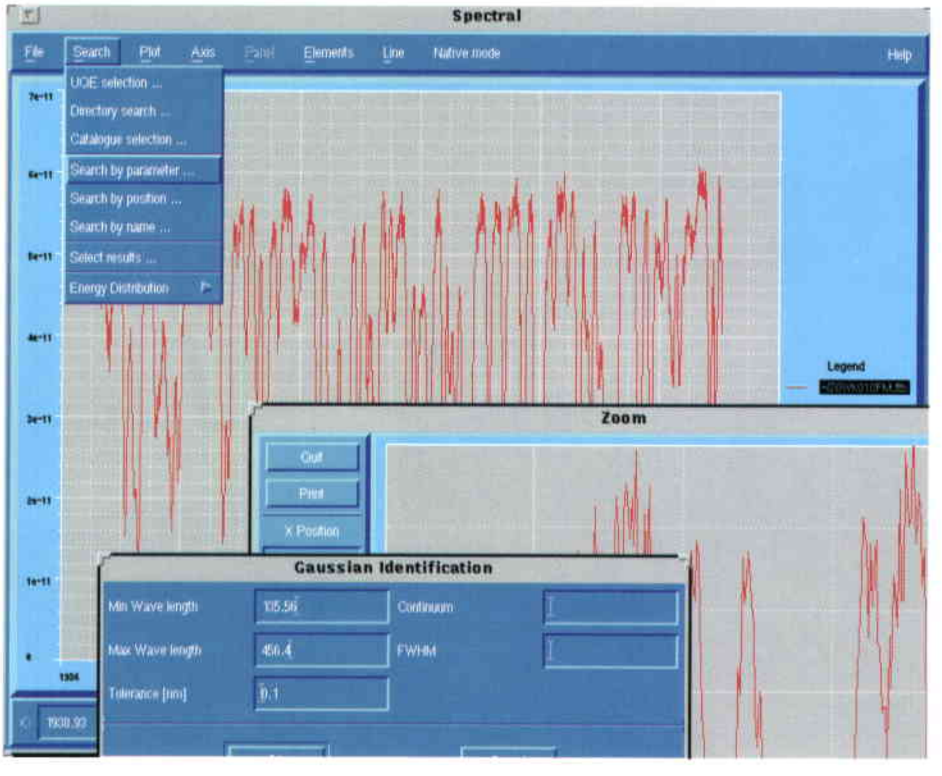

Figure 4. An example of the ESIS spectral application: the search menu (top left) and a plot of the spectral data

A few rather pragmatic choices were made with respect to the system architecture in order to achieve an operational and stable system with the limited resources available for the development:

1. Instead of applying a free and general query language, the ESIS Catalogue Browser has prioritised simplification through the definition of an essential set of client/server interactions. So-called field-constraints have been used in order to refine queries. Although restricted, the set of UQE interactions has allowed client software to be developed with sufficient functionalities.

2. The extensive use of meta data about catalogues and fields has allowed the transparent access to heterogeneous catalogues. With this approach, complexity due to data heterogeneity was moved from software coding to the creation and management of the Reference Directory. In addition, the software code has been made independent of any specific service, largely reducing the software and database maintenance tasks.

3. Choosing to keep the UQE stateless has contributed to the system's low complexity and more modular software components. The overhead of state transfers between client and server has not affected system performance.

The evolution of ESIS over the past year has been driven by several principles:

1. The existence of a system, well-defined in terms of user requirements and context.

2. Adaptation of existing archive-specific components to the overall system, thereby ensuring compatibility at all times.

3. Early involvement of the institutes that will provide the service with the transferred software, which allowed them to keep abreast of the status of the development process through each phase of the project. This guaranteed collaboration at the technical level throughout the development period and ensured that the software received was fully compatible with the target environment at the receiving institutes.

Acknowledgements

The authors wish to thank the Archive groups at the European Southern Observatory, the Canadian Astronomical Data Centre, and the HEASARC/ NASA for their technical assistance provided throughout the development period. Vitrociset and Cap Gemini were involved through industrial contracts.

The International Space Science Institute: A Vision Realised

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In May 1995, five Swiss astronomers and physicists, professors from the Universities of Basel, Bern, Geneva and Lausanne, were able to realise a project that they had envisioned for several years: the setting up of the International Space Science Institute (ISSI) in Bern, Switzerland.

Proposed to bring together scientists from around the World who have gathered specific data from various spacecraft, ISSI seeks to provide an opportunity for them to exchange and co-ordinate ideas, interpretations, approaches and data, to enhance their results. It offers a forum in which space scientists, astronomers, ground-based observers and theorists can work together on the joint analysis and interpretation of their data to achieve a deeper understanding of space-mission results. The ISSI approach was endorsed by the Inter-Agency Consultative Group (IACG) at its meeting on 28 September 1994.

Funding sought, funding found

While the support of the IACG was quite critical for the future of ISSI, only sufficient funding would guarantee success. Pro-ISSI – a society to promote the idea of ISSI, especially within Switzerland – was set up in May 1994 by the five professors (Johannes Geiss, Hans Balsiger, Bernard Hauck, André Maeder and Gustav A. Tammann) together with Hanspeter Schneiter, representing the Space Technology Group of the Verein Schweizerischer Maschinen-Industrieller (VSM/ Swiss Association of Machinery Manufacturers), and several other space specialists.

In August 1994, the Canton of Bern financed Pro-ISSI to outfit offices and provide a deficit guarantee. In early December 1994, the Swiss government's Federal Department of the Interior, through its Federal Office of Education and Science, provided substantial funding. In mid-December, the ESA Council unanimously decided to provide funding as well, roughly matching the Swiss contributions. A further grant for the scientific programmes was received from the Swiss National Science Foundation in the fall of 1995.

In January 1995, the Swiss firm Oerlikon-Contraves AG in Zurich provided the endowment to set up ISSI as a foundation. While ISSI is a foundation under Swiss law, its outlook is international, though its emphasis is on Europe because of the European aspects of its funding.

The Institute began to take shape in May 1995, when its Science Committee met for the first time. This group, made up of internationally known scientists active in the fields to be covered by ISSI, is chaired by David J. Southwood, of Imperial College, London. The members are drawn from a variety of universities in Austria, France, Switzerland and the USA and research institutes in France, Germany, Italy and Sweden. The Committee provides guidance for the science programme by advising the ISSI Directorate and the Board of Trustees.

ISSI's Board of Trustees is the governing body of the foundation. It appoints the Directors and broadly administers the Institute's resources. The Board, chaired by Hanspeter Schneiter of Oerlikon-Contraves AG, is made up of members of industry, IACG space agencies, the scientific community and two legal experts.

Out of the basement

Working long hours and with the help of a secretary and his assistant from the Physikalisches Institut at the University of Bern, Prof. Geiss moved the Institute from his cramped office in the basement at the University to the present more spacious offices nearby in September 1995. He was named Executive Director by the Board of Trustees, which then appointed a second Director, Prof. Bengt Hultqvist, formerly Director of the

Swedish Institute of Space Physics in Kiruna, and one of the original Science Committee members. Prof. Geiss's assistant, Dr. Rudolf von Steiger, became the senior scientist at the Institute.

With more space, there was room for more people: a computer and data engineer from Germany, Martin Preen; an Institute programme manager from Italy, Dr. Vittorio Manno; and an administrator/public relations specialist from the USA, Diane Taylor. A secretary, Gabriela Nusser-Jiang, completes the present full-time staff.

While the staff was coming together, Prof. Geiss and Dr. von Steiger were busy organising the first workshop on 'The Heliosphere in the Local Interstellar Medium', which took place in mid-November 1995. About fifty scientists – from Germany, France, Great Britain, Italy, Russia, Poland, Japan and the USA, as well as Switzerland, representing a variety of universities and research organisations, including ESA – compared their data from more than twelve different spacecraft and discussed their interpretations during the week-long meeting.

Members of the ISSI staff together with some 50 scientists from around the World, who gathered in Bern in November 1995 for the first ISSI Workshop on 'The Heliosphere in the Local Interstellar Medium' (photo. U. Lauterburg)

'A number of very interesting results about the interaction of the Solar System with its environment were presented and debated', Prof. Geiss reported after the workshop. Among these were the results on how the heliosphere – the expanding atmosphere of the Sun – ploughs through the 'hydrogen wall' of interstellar gas, presented by Rosine Lallement of the Service d'Aéronomie of CNRS, Verrières-le-Buisson (near Paris), Jeffrey Linsky of the University of Colorado at Boulder, and Vladimir Baranov of the Institute for Problems in Mechanics at the Russian Academy of Sciences in Moscow. He was also fascinated by the discovery by Eberhard Grün (Max-Planck-Institut für Kernphysik, Heidelberg) of interstellar grains penetrating deep into the inner Solar System. *'I feel we got off to a good start'*, Prof. Geiss continued, *'now we have to keep up the momentum!'*.

Science programme identified

To do this, based on the advice of the Science Committee, ISSI has forged ahead with its science programme. It has identified four major areas of interest in Solar System science: heliospheric physics, solar-terrestrial physics, solar wind and solar processes and cometary physics and chemistry, all leading to investigations of the origin of the Solar System and the relevance of Solar System exploration for the Earth sciences, astrophysics and cosmology.

Within the four areas, specific themes are selected and projects organised. Each project is led by an ISSI staff member or a member of the scientific community doing research in that specific area. A 'core group' of up to ten senior scientists chosen from the scientific community at large advises the project leader and assists in setting up the project, determining its goals and carrying it out.

The core group may convene several smaller working groups. These groups are to carry out their own additional data analysis as well as using and interpreting available analyses. Each group, with one to two co-chairs, may meet several times. A week-long workshop, with up to fifty or so participants, generally rounds off the project. However, if needed, this scheme may be repeated, with a second or even a third workshop, following intervening periods of working-group activities. A main task of each project is to find a consensus on matters where there were originally differing points of view. If such a consensus is not possible, the differences are to be specified as clearly as possible in physical terms.

To document the work, each project is to produce a final report, in the form of a book which that will be part of the Space Sciences Series of ISSI and will be a 'state of knowledge/state of problem' treatise on the topic. The core group will be responsible for appointing the editors of the publication, which will appear within a year after the final workshop.

In order to facilitate the meetings, ISSI can provide some financial assistance for participants, who are chosen by the core group for their excellence in the field and an ability to contribute time and effort to the project. Because of its international nature, ISSI seeks to find scientists from around the World. The Science Committee, for example, now has twelve members and includes scientists from Hungary and Japan in addition to those from Europe and the USA.

ISSI is trying to find the best and the brightest in each of its areas of research, giving established scientists an opportunity and a forum to get together, and promoting younger, up-and-coming researchers and providing them with an opportunity to expand their horizons and contribute to the work of others.

Visiting Scientists

ISSI is not, however, just working groups and workshops. Beginning in mid-1996, ISSI plans to begin inviting Visiting Scientists to work together with ISSI staff in doing research on specific projects at its facility. It is hoped that these scientists, ranging from young post-doctoral (or even graduate) students to full professors, will be funded by their home institutions, though the Institute expects to identify some fellowship and other outside funding opportunities. The Visiting Scientists will stay for periods ranging from one month to one year.

ISSI will make its infrastructure – including a variety of computers connected to the Internet, the computers at the University of Bern and the Swiss Scientific Computing Centre in Manno (Tessin) – available to these scientists, who will have the opportunity to work without outside distractions. They will be able to share data, interpretations, results and experiences and work together to publish articles in the scientific literature. ISSI's primary goal is to help the scientists do more and better science.

The ISSI infrastructure

ISSI is physically located on two floors of a newly renovated building close to the centre of Bern, about five minutes from the University's Physikalisches Institut and about ten minutes from the main railway station. Although it is not a part of the University, the Institute is connected to its computers. The workshop and working-group participants and Visiting Scientists will also have access to the Library at the Physikalisches Institut, in addition to the small, highly specialised library being developed at ISSI itself. Because of the diverse backgrounds of those involved, English is the working language of the Institute.

ISSI Activities Scheduled as of April 1, 1996

Themes	Date
Heliospheric Physics	
The Heliosphere in the Local Interstellar Medium • Workshop • Publication of Proceedings	 Nov. 1995 by Dec. 1996
Interstellar Dust • Working Group	 June 1996
3D Modulation of Cosmic Rays • Convenors Meeting • Workshop 1 • Workshop 2 • Publication of Proceedings	 Mar. 8-9, 1996 Sept. 17-20, 1996 Mar. 18-20, 1997 Winter 97/98
Solar-Terrestrial Physics	
Methods of Analysing Data from Clusters of Spacecraft • Working Group Meeting • Working Group Meeting • Working Group Meeting • Publication of ISSI Report	 Mar. 21-23. 1996 Jun 6-7, 1996 Nov. 7-8, 1996 Spring 1997
Source and Loss Processes of Magnetospheric Plasma (6 Working Groups) • Core Group • Working Group 1: Source Processes in the High-Latitude Ionosphere • Workshop 1 • Working Groups 1-6 • Publication of Proceedings • Workshop 2 • Publication of "Status of the Problem" Report	 Mar. 21-23, 1996 Jun 11-15, 1996 Oct. 1-5, 1996 Following WS in Oct. Summer/Fall 1997 Fall 1997 Summer/Fall 1998
Cometary Physics and Chemistry	
Physics & Chemistry of Comets • Working Group	 Jan. 22-23, 1996
Formation and Composition of Comets • Workshop	 Fall 1997
Four additional working groups have been formed	
Solar Wind and Solar Processes	
The Boundary of Coronal Holes and of Fast Streams • Working Group	 mid-1996
Solar Sources of Heliospheric Structure Observed out of the Ecliptic (in co-operation with Campaign IV of IACG Working Group I	 mid-1996
Activities will increase as SOHO data become available for interpretation in wider context	1997/98
Cosmological Questions	
Primordial Nuclei and Their Galactic Evolution • Advisory Group Meeting • Convenors Meeting • Workshop	 Jan. 25-26, 1996 June 1996 early 1997

Information always available

Additional information on ISSI and its programmes can be found in its World Wide Web home page, which is frequently updated. The address is:

http://ubeclu.unibe.ch/issi/

After the vision, the challenge

Now that ISSI is up and running, the vision has been realised – and the challenge begins: to make sure the programmes and projects are so interesting that the scientists keep coming.

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Climatologie océanique par satellite: un succès d'ERS

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Les paramètres météo-océaniques que sont la houle et le vent sont des facteurs déterminants de la conception des navires et des ouvrages en mer. Pour l'ingénieur, ces données proviennent de statistiques d'états de mer aux emplacements d'intérêt, dont les sources ne présentent pas toujours la qualité voulue.

La disponibilité de mesures de hauteurs significatives des vagues en provenance des satellites dotés d'altimètres a permis d'envisager d'y trouver une source nouvelle. Ce n'est toutefois qu'avec l'utilisation du SAR en mode vague d'ERS-1 et d'ERS-2, qu'on a pu répondre à l'essentiel des attentes des ingénieurs, pour lesquels la période et la direction de la houle ne peuvent être ignorées. Les satellites offrent une couverture dense de la surface des océans, et après plusieurs années d'exploitation, il est devenu possible de les utiliser à la construction de statistiques fiables, comme l'illustre le service CLIOSat, développé par Ifremer et MétéoMer.

Besoins des utilisateurs en paramètres météo-océaniques

Pour la construction de navires ou de plates-formes offshore, comme lors de la préparation d'opérations de remorquage ou d'installation sur site, on recherche la statistique des conditions qu'on sera susceptible de rencontrer tant aux moments cruciaux que dans des conditions normales d'opération. On peut distinguer trois types de conditions déterminantes pour le dimensionnement: communes, pour prévoir la fatigue des matériaux, extrêmes, pour parer aux tempêtes exceptionnelles, et critiques, pour éviter que des conditions sévères, mais non extrêmes, ne surviennent au moment inopportun d'une situation délicate.

La fatigue des structures en mer

La fatigue des matériaux est la conséquence de charges alternées répétées. Sous l'effet de ces charges, des micro-fissures s'initient dans les matériaux, principalement l'acier, puis se propagent et pourraient même conduire à la ruine d'une structure qui ne serait pas redondante et où ces fissures n'auraient pas été détectées à temps. La présence dans les plates-formes offshore de nombreuses jonctions de barres par des noeuds tubulaires soudés introduit, de par les soudures, des hétérogénéités et des défauts microscopiques à partir desquels les fissures peuvent se produire: dès la conception ce risque doit être pris en compte. Le problème est le même pour les navires, en ce qui concerne les tôles et les éléments raidisseurs (couples, lisses, cloisons).

La principale source d'efforts alternés en mer est bien évidemment la houle. Il s'y ajoute dans nombre de cas une réponse résonante de la structure, à des vibrations d'origine artificielle (machines, lignes d'arbre) ou naturelle (turbulence, vent, courant). Le vent et le courant peuvent également représenter des facteurs d'accentuation de l'intensité des efforts dus à la houle (Fig. 1).

On caractérise la fatigue par un coefficient d'endommagement, calculé à partir des contraintes dans le matériau, qui s'incrémente au fur et à mesure des efforts subis, et pour lequel la réglementation impose de ne pas dépasser un seuil donné sur l'ensemble de la durée de vie de l'ouvrage.

L'endommagement dû à l'action directe de la houle varie comme une puissance comprise entre 2 et 5 de la hauteur significative, suivant le type de structure et la nature de l'acier utilisé, ordinaire ou à haute limite d'élasticité. Il est d'autre part proportionnel au nombre de cycles alternés de chargement, et donc inversement proportionnel à la période de la houle. On voit donc l'importance de connaître avec précision la hauteur significative de la houle pendant toute la durée de vie prévisible de la structure, l'endommagement y étant très sensible. La période ayant une influence moindre, une précision inférieure peut être acceptée en ce qui la concerne. Toutefois, la période pourrait s'avérer déterminante pour certains types de structures dont elle gouverne la résonance. Même dans ce dernier cas, on évite la plupart du temps de risquer cette résonance, et on garde une large marge de sécurité autour des périodes propres de la structure, si bien qu'une précision de l'ordre de la seconde est suffisante.

Les conditions extrêmes

La réglementation, tout comme les intérêts des opérateurs, ont fixé des niveaux de risque à ne pas outrepasser pour les biens et les personnes à la mer. Par exemple, en offshore, la probabilité de ruine d'une structure portant du personnel lors d'une année quelconque de sa durée de vie ne doit pas excéder 1%. Cette condition est exprimée dans le langage courant comme centenale, ou ayant une période de retour de cent ans.

On doit donc estimer avec une excellente précision la distribution des conditions auxquelles l'ouvrage sera soumis, afin de pouvoir l'extrapoler, avec une confiance suffisante, à des niveaux de probabilité annuelle inférieurs à 10^{-2}. De plus, ces conditions extrêmes résultent de la conjonction de plusieurs facteurs : houle, vent, courant, qui, pris individuellement, ne causeraient pas nécessairement le même niveau de réponse. Il faut, pour savoir comment les combiner, disposer des distributions conjointes ou conditionnelles des différents paramètres.

Chacun de ces phénomènes doit également être décrit de manière détaillée: on calculera en effet le plus souvent une structure en simulant l'effet de la vague dite de design. La hauteur de cette vague individuelle se déduit de la hauteur significative de l'état de mer correspondant par l'application de modèles simples et bien validés. La période de la vague individuelle détermine la cinématique dans l'eau, qui elle-même définit les forces hydrodynamiques qui s'exercent sur la structure. Cependant, cette période ne peut se déduire de la simple hauteur de la vague, mais demande que soit connue la période moyenne de l'état de mer. D'autre part, une structure offre généralement plus de résistance dans certaines directions que dans les autres. Il importe donc de connaître les directions dans lesquelles se présenteront les sollicitations maximales pour implanter l'ouvrage en conséquence (Fig. 2).

En résumé, la houle représentant la source principale des efforts, on cherchera à disposer de la hauteur significative centenale, de la distributions des périodes associées, de celle des directions correspondantes, des conditions de vent associées, et éventuellement de courant, encore que le courant soit souvent largement indépendant des phénomènes précédents et quasi-déterministe.

Figure 1. Navire sous l'effet de la houle

Les opérations en mer

L'exploitation pétrolière offshore se trouve à l'origine de transports océaniques inhabituels, comme le remorquage, en flottaison ou sur barge, de plates-formes entières ou d'importants modules composant les installations à bord, depuis les chantiers de construction jusqu'au lieu d'implantation finale. L'installation en place est alors elle aussi une opération délicate. Elle demande en particulier de bénéficier d'un créneau météo-océanique de conditions inférieures à un seuil donné, qui peut lui-même dépendre des moyens choisis pour mener à bien l'opération.

En ce qui concerne les transports, les mêmes types d'études préparatoires que pour les structures doivent être conduits: fatigue durant le trajet, et conditions extrêmes rencontrées. La fatigue se calcule pour une durée plus courte, mais concerne des composants de la structure qui sont sollicités d'une manière inhabituelle, ainsi que le système d'arrimage sur la barge, et peut donc jouer un rôle déterminant dans le dimensionnement. Les statistiques météo-océaniques cherchées sont alors mensuelles ou trimestrielles. Elles concernent la hauteur significative de la houle, sa direction par rapport au trajet du convoi, l'existence possible de houles croisées, les périodes susceptibles d'engendrer des réponses résonantes en roulis, et les occurrences simultanées de vents forts, du fait du fardage important de la structure remorquée. La zone considérée s'étend, au long des routes possibles, sur de grandes distances.

Comme une structure fixe, un transport doit être dimensionné en fonction des conditions de réponse extrême. Cependant, compte tenu d'une durée d'exposition bien moindre et parfois de la possibilité de gagner un abri, on utilisera des conditions décennales, voire annuelles. Les paramètres influents sont les mêmes que pour la fatigue, et on a là, encore plus que pour les structures fixes, un important besoin de statistiques conjointes.

Les opérations sont principalement conditionnées par la hauteur significative. L'essentiel de l'aspect météo-océanique y réside dans la prévision à court terme en temps réel, mais les statistiques jouent auparavant un rôle important pour les études de faisabilité et le choix des moyens mis en oeuvre, comme par exemple la capacité de levage de la grue.

Une réponse aux besoins: les mesures satellitaires

Les enjeux économiques liés à l'exploitation pétrolière offshore sont considérables. Le coût d'une plate-forme de production se chiffre le plus souvent en centaines de millions de dollars, et peut même pour certaines dépasser le milliard de dollars. Une journée de retard dans une opération peut faire perdre plusieurs centaines de milliers de dollars. De telles sommes ne peuvent se risquer sur le coup de dés d'une connaissance imprécise des conditions météo-océaniques.

Faute d'instrumentation adéquate, la pratique courante consistait jusqu'à présent à rétro-simuler les conditions de mer lorsque le budget le permettait, ou à se contenter des observations consignées dans un atlas, comme le GWS (Global Wave Statistics). Malgré tout le soin apporté tant aux observations par les commandants de navires, qu'à leur compilation par les auteurs de ces ouvrages, il n'est pas possible de se libérer des limitations inhérentes à ce type de données. On peut ainsi citer l'imprécision de la mesure par observation humaine, la résolution spatiale insuffisante en dehors des grandes routes maritimes, ou les biais statistiques introduits par le contournement des tempêtes par les navires et par l'effet de l'état de la mer sur leur vitesse, et donc les proportions inégales de temps passé dans les zones de beau ou de mauvais temps.

Les modèles de rétro-simulation eux-mêmes ne sont pas exempts de reproches. Ils sont très sensibles à la qualité des champs de vent utilisés, qui sont souvent mal connus, en particulier dans l'hémisphère sud, bien que des progrès considérables aient été récemment réalisés grâce au recalage par rapport aux champs de vent mesurés par satellite, en particulier par le diffusiomètre d'ERS. Ils présentent une forte inertie et rendent mal compte des changements rapides de temps. La propagation lointaine de la houle reste imparfaitement modélisée. Ils

Figure 2. Plate-forme attaquée par la houle

sont ajustés à l'aide des conditions les plus fréquentes, et non en conditions extrêmes, avec les conséquences que cela implique pour ces dernières.

L'ingénieur et l'océanographe ont souvent des exigences différentes. L'ingénieur cherchera à caractériser un état de mer par sa hauteur significative, H_S, qui représente l'énergie des vagues. Il s'intéressera également à la période, qui détermine la cinématique, et donc les forces sur les structures, qui peut décider de comportements résonants, et qui définit le nombre de cycles en fatigue. La direction, qu'elle soit relative au cap suivi par un navire ou à celle de meilleure résistance d'un ouvrage, peut présenter un certain intérêt.

Le vent est fréquemment moins déterminant que la houle, mais son action doit cependant être ajoutée à celle des vagues. En certains endroits, les courants peuvent avoir une influence importante, mais dans la plupart des cas, les conséquences d'une amélioration de leur connaissance sont sans commune mesure avec celles de la réduction des incertitudes sur la houle extrême, par exemple.

Hauteur significative des vagues

La hauteur significative habituelle en ingénierie est définie par 4σ, où σ est l'écart-type de l'élévation de la surface libre, traditionnellement estimé en un point fixe sur une durée de l'ordre de 20 minutes. Il est nécessaire d'estimer avec une excellente précision la partie haute de sa distribution à long terme. En effet, une incertitude supplémentaire de 50 cm sur les hauteurs significatives mesurées se traduirait par environ 1,50 m sur la vague maximale, et pourrait augmenter le coût d'un ouvrage typique de près de 10%.

Les H_S altimétriques sont mesurées comme quatre fois l'écart-type de l'élévation de la surface libre sur un ovale d'environ 40 km^2. Si les vagues se déforment au cours de leur propagation, leurs propriétés statistiques globales ne varient que lentement, et on peut estimer que la mesure altimétrique de H_S est équivalente à celle qui serait effectuée au point fixe, au centre de la tache, pendant une durée égale au diamètre de la tache divisé par la vitesse de groupe. La qualité de l'estimateur dépend, elle, du nombre de vagues utilisées. En se fixant des conditions typiques, soit une période des vagues de 10 secondes, et un rapport de 10 entre longueur de crêtes et longueur d'onde, il y a environ 160 vagues dans une tache, et donc un nombre comparable à ce qui est observé en 20 à 30 minutes au point fixe. L'estimateur de H_S fourni par l'altimètre d'un satellite est donc très semblable à celui de la pratique courante des mesures in situ.

Des calibrations effectuées par rapport à des mesures quasi-simultanées et quasi-colocalisées de bouées ou de houlomètres radar installés sur des plates-formes pétrolières ont montré que les différences n'excèdent pas 30 cm, validant ces résultats bien au delà des attentes lors des spécifications initiales.

En raison des difficultés à trouver des mesures colocalisées en temps et en espace, ces calibrations pourraient n'apparaître que peu probantes, surtout pour des conditions s'écartant de la norme. Quand on compare les mesures effectuées sur la bouée Béatrice de séparation du trafic d'Ouessant avec celles de l'altimètre de Geosat pendant la même période, on constate qu'en dehors des faibles états de mer où les limites de sensibilité des capteurs apparaissent, les erreurs sur la distribution à long terme ne dépassent vraisemblablement pas 10 cm.

Toutefois, les données altimétriques requièrent plus de soin dans le pré-traitement que celles d'autres sources, en particulier au voisinage des côtes où il faut quelques secondes à l'altimètre pour se stabiliser quand la trajectoire quitte la terre, et là où des îles sont susceptibles de fausser la mesure radar.

Cela signifie également que les zones côtières ne peuvent bénéficier qu'indirectement de l'apport des mesures satellitaires, par le biais de modèles de propagation appliqués à des spectres mesurés au large.

Périodes des vagues

La période apparente des vagues peut être caractérisée à partir de la représentation fréquentielle de l'élévation de la surface libre (spectre). On utilise principalement deux valeurs caractéristiques: la période du pic du spectre, qui correspond en quelque sorte à la composante la plus énergétique de la houle, et la période moyenne, laquelle correspond à la décomposition d'un historique de surface libre en vagues successives, la séparation se faisant au passage par le niveau moyen.

L'ingénieur pourra aussi souhaiter quantifier l'aspect 'multipic' du spectre, pour reconnaître des états de mer où se combinent des houles et des mers du vent de périodes et de directions différentes.

Pour les mesures satellitaires, les périodes sont issues du SAR en mode vagues, qui est le seul capteur à pouvoir les mesurer. En mode vague, l'imagette SAR fait 5 km de côté, elle est obtenue en faisant la moyenne de trois vues successives, ce qui réduit la taille du pixel à 16×20 m, et elle est fournie en routine sous forme de spectre d'image avec une définition réduite (12 raies en fréquence et 12 secteurs directionnels dans le demi-plan). Le sens de propagation ne pouvant être discriminé, l'image est en effet symétrique par rapport à l'origine.

On peut comparer la transformée de Fourier bi-dimensionnelle de l'imagette à un spectre directionnel des pentes de la surface libre. Toutefois, plusieurs phénomènes compliquent la relation entre cette transformée de l'imagette et le spectre directionnel de la houle, principalement:

1. l'intégration spatiale à effectuer pour passer des pentes à l'élévation de la surface libre,
2. l'interaction hydrodynamique entre vagues et vaguelettes,
3. le 'range bunching': influence de l'élévation de la surface libre sur le temps de retour du signal,
4. le 'velocity bunching': effets du déplacement des facettes induit par la vitesse orbitale à la surface des vagues, qui introduit un décalage Doppler dans le signal réfléchi.

De plus, la transformée de l'imagette est 'indiscriminée', c'est-à-dire qu'elle contient une ambiguïté de 180° sur la propagation des vagues.

Ce processus d'imagerie SAR peut être modélisé par un ensemble de transformations parfois fortement non-linéaires. La résolution du problème inverse a fait l'objet de recherches poussées, en particulier en Allemagne, en Norvège et en France. Il utilise l'apport d'une 'ébauche', spectre directionnel calculé à partir d'un modèle numérique simulant la houle à partir des champs de vent, d'une part pour discriminer entre les deux sens possibles de propagation, d'autre part pour compléter dans le domaine des hautes fréquences (mer du vent) l'information rendue inaccessible par la taille des pixels de l'imagette et par l'atténuation due au 'velocity bunching'.

La Figure 3 illustre ces points en présentant un spectre SAR observé et le spectre directionnel de houle reconstruit par inversion.

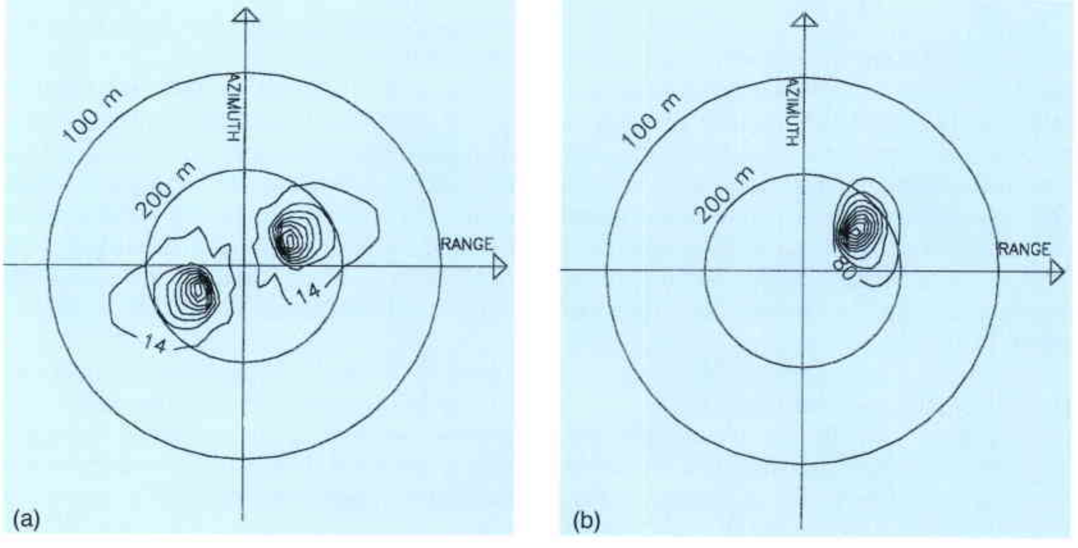

Figure 3. Spectre directionnel SAR observé (a) et inversé (b)

La période du pic du spectre, T_p, est robuste vis-à-vis de la procédure d'inversion des spectres SAR. Toutefois, il s'agit plus souvent d'un paramètre de climatologue que d'ingénieur, ce dernier s'intéressant principalement à la période moyenne de passage par le niveau moyen, déterminante pour le calcul en fatigue.

La période moyenne T_z peut s'estimer à partir des moments spectraux d'ordre 0 et 2 (barycentre du spectre SAR), on parle alors de $T_{0,2}$. Toutefois, elle est alors fortement affectée par les effects sur le moment d'ordre 2 de la coupure azimutale liée au 'velocity bunching' et de la gamme de fréquences couverte. Il est donc nécessaire de compléter le contenu spectral par une information haute fréquence adéquate.

Il est reconnu que la qualité de simulation de la mer du vent dépend quasi-exclusivement de l'exactitude des champs de vent utilisés. Or, la fauchée de mesure du diffusiomètre recouvre largement la position de l'imagette SAR, permettant ainsi un calcul de grande qualité, puisque simultané et colocalisé. On peut donc compléter avec un excellent niveau de confiance les spectres issus de l'inversion SAR grâce à un modèle local qui génère la partie manquante à partir d'un champ de vent recalé sur la mesure diffusiométrique.

La précision sur T_z corrigée est alors de l'ordre de celle sur T_p, qui a pu être estimée à environ 1 s à partir de comparaisons avec des mesures de bouées.

Par contre, les H_S en provenance du SAR sont largement affectées par la discrétisation et l'étroitesse de bande des produits fournis. Lorsque cela est possible, on recommandera donc d'utiliser de préférence les H_S altimétriques.

Cependant, on utilise généralement les périodes dans des distributions conjointes qui sont robustes vis-à-vis d'erreurs limitées sur les hauteurs, et pour lesquelles une moins grande précision est requise car on s'intéresse d'abord aux valeurs les plus probables. On peut d'ailleurs également, dans une certaine mesure, améliorer les H_S SAR à partir des mesures altimétriques simultanées les plus voisines (200 km) et du modèle ayant servi à constituer les ébauches. Cela permet que les distributions conjointes hauteurs-périodes ou hauteurs-directions soient suffisamment précises pour les besoins d'ingénierie.

Directions des vagues

De même, pour les périodes, la direction moyenne souffre d'une large incertitude en raison des atténuations et coupures haute fréquence. L'incertitude peut être réduite par l'adjonction d'une mer du vent calculée à partir des champs de vent du diffusiomètre. Toutefois, du fait de la dépendance de la cinématique en cos (θ), la direction moyenne ne représente que très rarement un paramètre plus pertinent que la direction du pic principal d'énergie.

L'ordre de grandeur de l'incertitude sur la direction des pics principaux a pu être évalué, toujours par comparaison avec des mesures de bouées, à environ 15°, soit le pas de discrétisation des produits SAR mode vague.

Le vent

La limitation dans la mesure du vent altimétrique aux alentours de 22-25 m/s limite ses applications à l'estimation des conditions les plus fréquentes sur une zone. Le vent issu du diffusiomètre est moins limité, mais reste peu fiable dans les très grandes valeurs. Le calcul des extrêmes risque donc d'en être pénalisé.

En raison des difficultés à le mesurer in situ, il est délicat d'avancer des chiffres quant à la précision des mesures diffusiométriques du vent, précision dont l'ordre de grandeur est sans doute meilleur que 2 m/s pour la vitesse, et une dizaine de degrés pour la direction. Elles sont cependant généralement considérées comme d'aussi bonne qualité que celles issues d'autres capteurs. Elles répondent donc bien aux besoins des ingénieurs, qui se satisfont déjà de ces dernières.

Critères géographiques

Les cycles orbitaux des satellites sont fréquemment assez longs par rapport aux échelles de temps des variations de la hauteur significative. Lorsqu'on cherche les caractéristiques en un point donné, la question est donc de savoir jusqu'à quelle distance on peut s'en éloigner pour recueillir des données, sans pour autant cesser de considérer des mesures relevant d'une population statistique unique.

Une délimitation attentive de la zone par un météorologue, et l'enrichissement de la distribution par la propagation vers la zone des tempêtes mesurées sur une plus grande région l'englobant, se sont avérés plus efficaces qu'une méthode de tests statistiques automatiques sur des régions circulaires et annulaires.

La taille de la zone ainsi définie est habituellement telle qu'elle est recoupée par un satellite unique une à deux fois par jour en moyenne. Plusieurs états de mer peuvent généralement être identifiés sur chacun de ces segments de trace. Les produits SAR mode vague ne sont mesurés que tous les 200 km environ, et la cadence moyenne est donc inférieure, de l'ordre d'un tous les deux jours. Ce taux semble cependant suffisant pour estimer l'allure générale des distributions des périodes et directions conditionnellement à H_S.

Critères de durées observées

Les statistiques sont rapportées, en ingénierie, à des durées. Il peut s'agir du temps pendant lequel une action s'exerce sur un ouvrage, ou du temps d'exposition à un niveau de risque donné.

Les satellites utilisables pour la mesure météo-océanique sont exclusivement des satellites défilants, et le problème se pose donc de rapporter leurs mesures à des durées pour pouvoir exprimer la signification réelle des statistiques. D'autre part, les satellites ne passent exactement au-dessus du même point qu'avec une période orbitale de plusieurs jours. Il importe donc de déterminer si des passages sur des orbites voisines peuvent être regroupés pour la constitution d'un unique échantillon statistique.

On doit donc définir une notion de durée équivalente, reposant sur celle des états de mer. Un état de mer au point fixe peut être défini comme un morceau stationnaire du processus des hauteurs significatives, et identifié, par une analyse adéquate. En ne conservant alors qu'une valeur de hauteur significative pour tout l'état de mer, on se crée une indépendance statistique suffisante entre les événements pour pouvoir utiliser les procédures d'extrapolation classiques et déterminer les hauteurs significatives extrêmes nécessaires dans les phases de conception.

Les mêmes méthodes de découpage en morceaux stationnaires peuvent être appliquées aux hauteurs significatives altimétriques le long des traces d'un satellite, fournissant ainsi des portions (spatiales) stationnaires. En utilisant les considérations de vitesse de groupe et de nombres de vagues évoquées plus haut, on peut associer des durées équivalentes à chacune de ces portions. On peut alors comparer le nombre d'états de mer observés par satellite sur une zone et pendant une période données, au nombre total qui aurait été mesuré au point fixe par un enregistrement continu, et en déduire un taux de couverture temporelle.

Lorsqu'on souhaite extrapoler aux conditions extrêmes, on peut améliorer la procédure en recherchant, dans les archives météorologiques, les plus fortes tempêtes ayant affecté la zone. Si certaines de ces tempêtes peuvent avoir été 'manquées' par la mesure satellitaire, elles ont néanmoins la plupart du temps été mesurées, à un stade antérieur ou postérieur, en un lieu peu éloigné. On peut alors modéliser leur évolution recalée sur cette mesure, et enrichir la queue de la distribution correspondant à la zone des tempêtes qui l'ont affectée. Bien entendu, on doit alors utiliser une méthode d'extrapolation qui ne repose que sur les mesures au delà d'un certain seuil.

Les produits ERS

Avant de parler des produits ERS utilisés en climatologie, leur génération et leur distribution à la communauté des utilisateurs, il est fort utile de repenser aux années '80 lorsque le Comité consultatif pour les programmes de télédétection de l'ESA recommanda, après de longs débats, d'embarquer à bord de ERS-1 un SAR imageur et de l'opérer également en un mode appelé 'mode vague'. Le mode vague proposé consiste en une séquence d'observations du SAR, tous les 200 km, sur une période de temps très courte afin de permettre l'enregistrement des données à bord du satellite. Le compromis choisi a permis une exploitation globale des océans, tout en conservant l'information sur les caractéristiques essentielles des vagues. En fait, comme cela a déjà été mentionné, les données du SAR en mode vague ont joué et jouent un rôle essentiel dans l'opérationalisation de l'utilisation des données ERS en particulier pour la climatologie océanique.

A l'époque où la mission a été conçue, il était facile de supporter l'embarquement d'un radar altimètre pour mesurer la hauteur des vagues alors qu'il n'était pas évident de justifier un SAR imageur pour fournir le spectre des vagues. En effet, les mesures du radar altimètre sont très convaincantes: l'altimètre génère une impulsion très courte par comparaison à la distance de la crête aux creux des vagues et explore très précisément les ondulations de la surface de la mer de sorte que la hauteur des vagues peut être aisément et précisément extraite de la forme du signal retourné. A l'inverse, les mesures du SAR en mode vague sont plus complexes à analyser. D'une part, si les vagues sont visibles, personne ne peut comprendre sur l'image la direction de leur mouvement. D'autre part, le SAR pour produire une image, a besoin de construire une antenne synthétique. Ce mécanisme demande un temps considérable, de l'ordre d'une seconde, et le mouvement des vagues crée alors de sévères distorsions dans l'image. De plus, un spectre de vague peut être constitué d'un large éventail de composantes spectrales, alors que le SAR ne peut ni reconstituer les vagues ayant de courtes longueurs d'onde, étant limité en résolution, ni reconstituer les vagues ayant de très longues longueurs d'ondes à cause de la période limitée d'observation. Le choix du SAR en mode vague avait été fortement soutenu par une équipe d'experts et plus particulièrement par le professeur Hasselmann sur la base d'une synergie entre le développement des modèles de vagues et les mesures du satellite et vice versa. C'est effectivement ce qui est arrivé ces dernières années, avec le développement de techniques d'assimilation des données des satellites dans les modèles.

Les mesures satellitaires utilisées en climatologie océanique, sont, en plus de celles du SAR en mode vague, les mesures de vagues et de vent issues de l'altimètre et les champs de vent provenant du diffusiomètre, c'est-à-dire toutes les mesures des capteurs dits 'à basse cadence' (low bit rate - LBR) à l'exception des mesures de l'ATSR et de la mesure radar de l'altimètre.

Immédiatemment après leur acquisition, les mesures sont traduites en produits utilisateurs dans les stations d'acquisition de l'ESA puis distribuées et délivrées en moins de 3 heures. Ces produits, URA (User Radar Altimeter), UWI (User Wind) et UWA (User Wave) sont appelés 'produits à livraison rapide' (fast-delivery products - FD). Ces données peuvent être déjà utilisées pour les applications liées à la connaissance des états de mer. Une base de données climatologiques peut être alors construite à partir d'acquisitions journalières de ces produits à livraison rapide.

Ceci n'est bien sûr réalisable que dans le cas de projets développés en parallèle à la distribution des données ERS LBR-FD, d'où l'importance de disposer d'une archive et de services 'off-line' pour ces produits. Il existe d'autres raisons justifiant le maintien d'un service off-line. En effet, la production FD a subi de nombreuses évolutions depuis la période initiale de validation jusqu'à la phase de production de routine et les algorithmes, et donc les logiciels de traitement associés, ont été plusieurs fois modifiés. A fin de disposer de séries historiques homogènes, il a été nécessaire de re-traiter de larges quantités de données et particulièrement celles du SAR en mode vague et du diffusiomètre. Ceci explique l'importance considérable, pour l'application que nous présentons ici, des centres de traitement et d'archivage des données (Processing Archiving Facilities - PAF) qui fournissent off-line également les données FD. Le centre de traitement et d'archivage des données basse cadence ERS, pour les applications océanographiques, est situé en France, dans un bâtiment du Centre de Brest de l'Ifremer. Ce PAF est appelé CERSAT (Centre ERS d'Archivage et de Traitement). Etant lié à un institut de recherche océanographique, il a joué et joue actuellement un rôle important dans le développement des applications pour l'environnement marin.

Une réponse opérationnelle: CLIOSat

L'ESA a accordé à MétéoMer plusieurs projets pilotes depuis 1991, qui ont permis les études de faisabilité et les développements conduisant à l'élaboration de CLIOSat. Le CNES, dans le cadre du programme AVALSAR, a financé les projets de l'ESA et particulièrement ceux relatifs à l'extraction de paramètres directionnels à partir de mesures SAR mode vague. Les années de mesures disponibles actuellement ont été validées par rapport à des mesures in situ dans le cadre de différents travaux de recherche menés par l'Ifremer et de recherche finalisée menés par MétéoMer dans le cadre du CLAROM (Club pour les Actions de Recherche sur les Ouvrages en Mer) et le FSH (Fonds de Soutien des Hydrocarbures).

Concept

Depuis quelques années, les industriels ont recours aux données satellitaires pour la caractérisation météo-océanique fine des sites spécifiques, particulièrement dans les zones peu ou imparfaitement pourvues en mesures in situ.

A cet effet, des méthodologies opérationnelles ont été développées en Europe, plus particulièrement à MétéoMer qui combinent données satellitaires, modèles météo-océaniques, stochastiques, bathymétrie, etc. La complexité de ces procédures s'accroît principalement avec le caractère côtier des sites étudiés. Les délais de réalisation de tels travaux, de l'ordre de 4 à 6 semaines, représentent une réduction d'un facteur 10, au moins, par rapport aux coûts d'une campagne in situ.

Néanmoins, ces contraintes de coûts et de délais, bien que représentant un progrès énorme, limitaient, jusqu'à présent l'extension de l'usage des données satellitaires, car une information utile au niveau de la faisabilité d'un projet ou pour l'estimation rapide des conditions moyennes régnant le long d'un trajet donné, se doit d'être accessible de façon quasi-immédiate et à très faible coût. CLIOSat, réalisé conjointement par Ifremer et MétéoMer, a été conçu pour répondre à cette attente. En effet, les sept années de mesures actuellement disponibles et notamment, les quatre années de mesures directionnelles fournies par le SAR mode vague d'ERS-1 permettent, d'ores et déjà, l'établissement de climatologies complétant et affinant des traits déjà connus des climats maritimes.

Le concept de CLIOSat se base uniquement sur l'utilisation de mesures satellitaires de vents et de vagues fournies par les satellites Geosat, Topex-Poseidon et plus particulièrement ERS-1/2 qui, seuls, apportent les mesures spectrales d'états de mer et donc, les périodes et directions. CLIOSat s'appuie sur la constitution d'un système d'interrogation et d'archivage de toutes les données satellitaires de l'environnement marin disponibles à l'échelle mondiale, en vue de leur restitution rapide sous forme de produits climatologiques utiles aux ingénieries.

On distingue, en particulier, deux modes dans CLIOSat:
1. un atlas informatisé fonctionnant sur PC et présentant, pour 169 zones prédéfinies couvrant les océans, des statistiques annuelles et trimestrielles ainsi que les ordres de grandeurs des valeurs extrêmes de hauteur significative;
2. un service personnalisé, 'en ligne', destiné à fournir des produits climatologiques identiques à ceux de l'atlas, mais sur des zones et selon des critères établis à la demande.

Les paramètres ainsi fournis caractérisent des régions océaniques définies au préalable ou à la demande, mais ne correspondent cependant pas à des grandeurs à la côte ou à des sites d'extension très réduite. Par conséquent, ils peuvent ne pas suffire lors des phases poussées de conception d'ouvrages (design), mais conviennent à une rapide évaluation, au stade de l'avant-projet.

Elaboration de produits climatologiques

Cohérence climatologique

Une analyse des grandes tendances et des phénomènes météo-océaniques affectant les différentes parties des océans révèle l'existence de zones aux caractéristiques distinctes et bien définies, au sein desquelles les états de mer susceptibles d'être rencontrés appartiennent à la même population statistique. Contrairement aux observations de navires essentiellement regroupées le long des principales routes maritimes, la couverture dense, homogène et tout temps des océans et mers du globe offerte par les différents satellites d'observation de l'environnement marin autorise la fourniture de statistiques fiables de paramètres d'états de mer et de vent sur chacune des zones ainsi mises en évidence.

Dans l'Atlas CLIOSat, un découpage global et précis en zones de cohérence climatologique des mers et océans du monde a été effectué par un expert météo-océanographe. C'est dans ces zones de cohérence climatologique que les données satellitaires sont rassemblées puis traitées. Dans le cadre du service en ligne de CLIOSat, ce principe de cohérence est appliqué pour réduire au minimum la taille d'une zone caractérisant un site d'intérêt opérationnel. Cependant, en cas de zone côtière ou de faible extension géographique, on se heurtera au problème de la cohérence statistique du résultat; une solution, sortant du cadre propre à CLIOSat étant apportée par l'utilisation combinée de données satellitaires et de modèles météo-océaniques.

Constitution des produits climatologiques

La constitution des produits climatologiques repose sur les étapes suivantes:
— Traitement des données reçues des fournisseurs (Eurimage pour les données ERS-1/2, CNES-AVISO pour les données Topex-Poseidon) pour l'extraction de paramètres géophysiques utiles.
— Elaboration des données intégrées (vent, vagues).
— Archivage des données intégrées.
— Désarchivage et élaboration des statistiques constituant les produits climatologiques.

Parmi les données reçues des fournisseurs, on distinguera celles offrant des mesures directement exploitables après contrôle de leur qualité et correction de biais éventuels et celles requérant un traitement plus sophistiqué, telles les données issues du SAR ERS en mode vague fournies par Eurimage.

Pour la constitution d'histogrammes et de statistiques de hauteurs significatives et de force du vent, les mesures altimétriques de ERS-1 sont compilées avec celles issues de Topex-Poseidon et Geosat. Ceci permet, en effet, de disposer d'une durée de mesures de l'ordre de 7 années, avec une couverture particulièrement dense depuis l'exploitation du satellite Topex-Poseidon, en août 1992. Une analyse semi-automatisée, basée sur un test de vraisemblance, permet de s'affranchir d'éventuelles aberrations en particulier au voisinage des côtes ou en cas de perturbation du signal. Enfin, l'application de formules de corrections déterminées lors des campagnes de validation des altimètres permet de disposer d'un ensemble homogène de données fiables.

Les mesures de vent issues du diffusiomètre, force et direction, sont quant à elles, susceptibles d'être utilisées directement car on leur applique un algorithme correctif permettant la levée d'éventuelles ambiguïtés de direction par comparaison avec les sorties de modèles météorologiques classiques. Ces données servent à la détermination d'histogrammes de direction du vent et de diagrammes d'occurrences conjointes de force et direction. En revanche, on préférera leur substituer les mesures altimétriques pour l'élaboration d'histogrammes de forces du vent, la durée ainsi couverte, sept années, étant supérieure à celle offerte par les données diffusiométriques actuellement disponibles.

Les paramètres caractéristiques des états de mer, hauteurs significatives, périodes et directions, sont issus du traitement des données SAR en mode vague. La procédure utilisée, évoquée plus avant, est assez complexe. En effet, la relation entre la donnée initialement fournie (spectre d'intensité d'image analogue au spectre des pentes de la surface) et le spectre directionnel d'état de mer associé n'est pas linéaire et dépend aussi, dans une certaine mesure, de l'état de mer observé. De plus, cette donnée initiale présente une ambiguïté à 180° sur le sens de propagation de ses composantes. La méthode 'd'inversion' employée pour traiter l'ensemble des données SAR mode vague reçues nécessite l'usage de quatre années de champs de vents globaux afin d'obtenir, à l'endroit et à l'instant de chaque mesure, une ébauche de spectre d'état de mer nécessaire à la levée de cette ambiguïté. L'information sur les hautes fréquences, périodes inférieures à 7,5 s, absente du fait de la physique de la mesure, est restituée à partir d'un modèle utilisant en entrée les données de vent concomitantes issues du diffusiomètre. Le résultat des traitements ainsi effectués est ensuite analysé puis vérifié par des météo-océanographes, par rapport à des situations typiques ou extrêmes connues. On obtient ainsi, à l'échelle globale, une information spectrale directionnelle couvrant des périodes s'étalant de 2 à 25 secondes, dépassant de fait les limitations classiques des observations de navires liées à la difficulté, voire l'impossibilité, pour un observateur, d'estimer visuellement et à partir d'un repère mobile les périodes des houles supérieures à 10 s ou des états de mer à multiples composantes. L'analyse spectrale des données SAR mode vague traitées offre alors les moyens d'une étude fine de chacune des composantes spectrales. On peut ainsi présenter une description détaillée des états de mer multiples et discriminer parfaitement les périodes et directions des différents pics spectraux présents en leur sein (présence d'une ou deux houles et d'une mer de vent), mettant ainsi en valeur une simultanéité des phénomènes encore souvent insoupçonnée. Une fois déterminés ces différents pics spectraux, la direction du pic principal d'énergie peut être également évaluée. Enfin, comme évoqué précédemment, le calcul des moments spectraux d'ordre 0 et 2 permet également la détermination des hauteurs significatives et des période moyennes utilisées dans la construction de diagrammes d'occurrences conjointes.

Une sauvegarde des données ainsi traitées et validées est ensuite réalisée, constituant ainsi la base de données utile à CLIOSat. Son interrogation, selon des critères spatio-temporels, uniques et prédéfinis dans le cas de l'atlas CLIOSat sur PC, déterminés à la demande pour le service en ligne, permet alors l'extraction des informations qui constitueront par la suite histogrammes et diagrammes d'occurrences.

L'atlas CLIOSat sur PC

Les produits climatologiques présentés dans l'atlas CLIOSat sur PC ont été définis en accord avec un Comité d'expertise et d'orientation composé d'utilisateurs industriels de données climatologiques, représentés, en particulier, par les principales ingénieries françaises des domaines offshore, portuaires et maritimes.

Ainsi, l'Atlas de climatologies océaniques satellitaires CLIOSat disponible pour PC présente pour 169 zones de cohérence climatologiques prédéfinies par des experts météo-océanographes, des statistiques annuelles et trimestrielles de paramètres de vents et d'états de mer et des ordres de grandeur des valeurs extrêmes de hauteur significative (Fig. 4a-b). Utilisant les sept années de données altimétriques issues des satellites Geosat, Topex-Poseidon et ERS-1 et les quatre années de mesures directionnelles d'état de mer provenant du SAR mode vague embarqué sur ERS1, il offre les produits climatologiques suivants:

Des histogrammes

1. Vagues:
   — hauter significative
   — périodes pics (incluant houle et mer du vent)
   — directions pics (incluant houle et mer du vent).

2. Vent:
   — force
   — direction.

Des diagrammes croisés - vagues

1. Systèmes mer du vent et houle:
   — périodes pics/directions pics
   — périodes pics/hauteurs significatives
   — directions pics/hauteurs significatives

(chaque diagramme fourni avec le pourcentage des états de mers présentant de multiples composantes).

2. Etat de mer caractérisé dans sa totalité:
   — hauteur significative/période moyenne
   — hauteur significative/direction du pic principal.

Des diagrammes croisés - vents

— direction/force du vent.

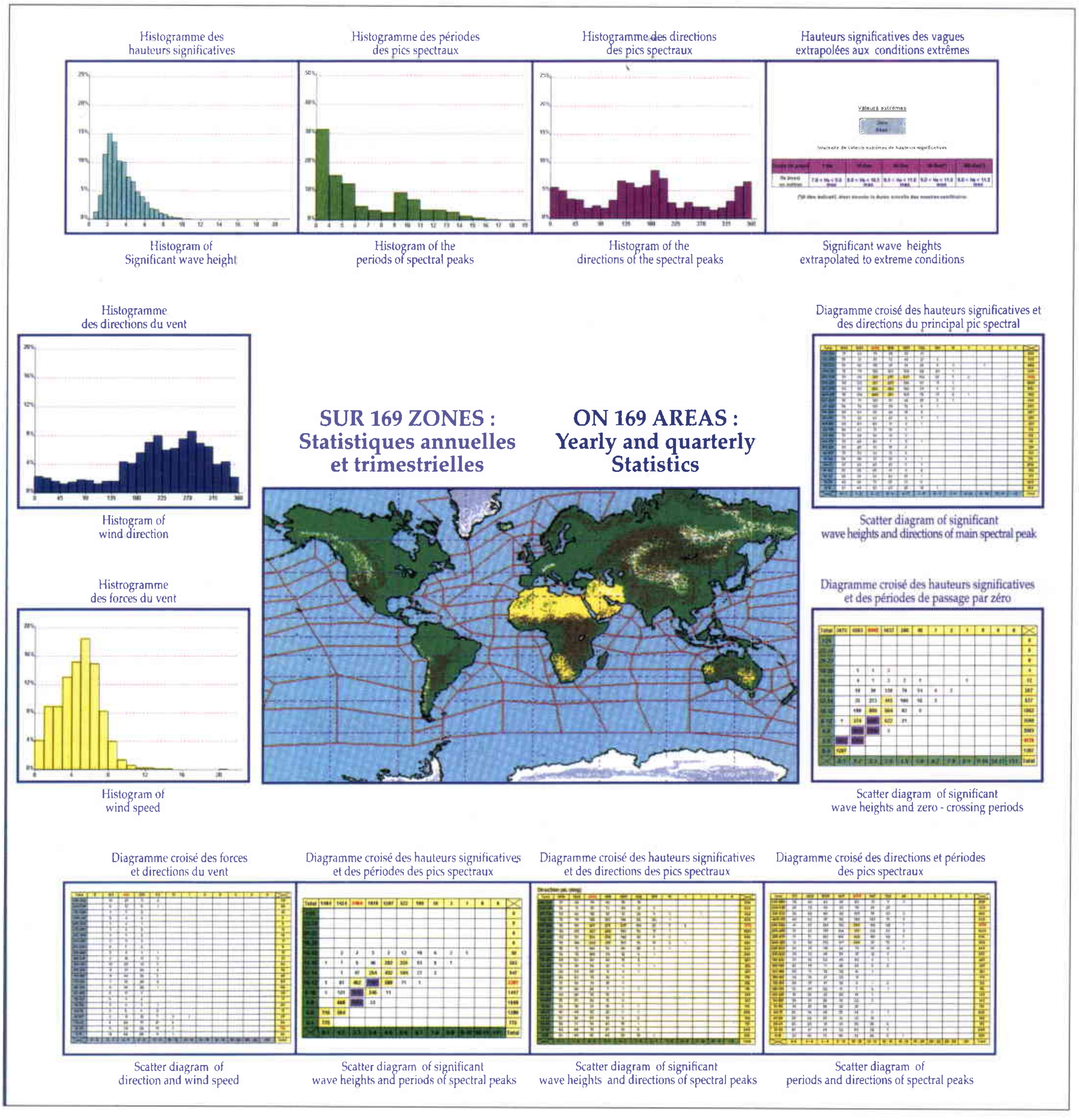

Figure 4a. Les 169 zones couvertes par l'Atlas CLIOSat

Des hauteurs significatives extrapolées aux conditions extrêmes

Pour chaque zone climatologique prédéfinie et pour chacune des durées considérées, l'Atlas CLIOSat fournit un intervalle dans lequel se trouvent, avec 90% de confiance, les valeurs extrêmes de H_S possibles. Cet intervalle traduit la disparité des états de mer due à l'étendue de zones prédéfinies, toutefois cohérentes climatologiquement.

Bien entendu, des réactualisations annuelles, rendues possibles par l'important flot continu des données et l'existence des programmes spatiaux à venir, sont prévues.

Service en ligne CLIOSat

Les informations présentées dans l'Atlas CLIOSat concernent les climatologies générales des zones prédéfinies par des experts météo-océanographes. Cependant, un utilisateur peut nécessiter des informations de type similaire, sur un site spécifique. Le service en ligne de CLIOSat permet à son utilisateur d'obtenir en 24 heures, sur une zone définie, selon son besoin, par ses soins ou à l'aide de spécialistes météo-océanographes et, selon des critères temporels personnalisés, des climatologies suffisamment précises pour pouvoir esquisser les grandes lignes d'un projet. Il repose sur les mêmes principes d'élaboration

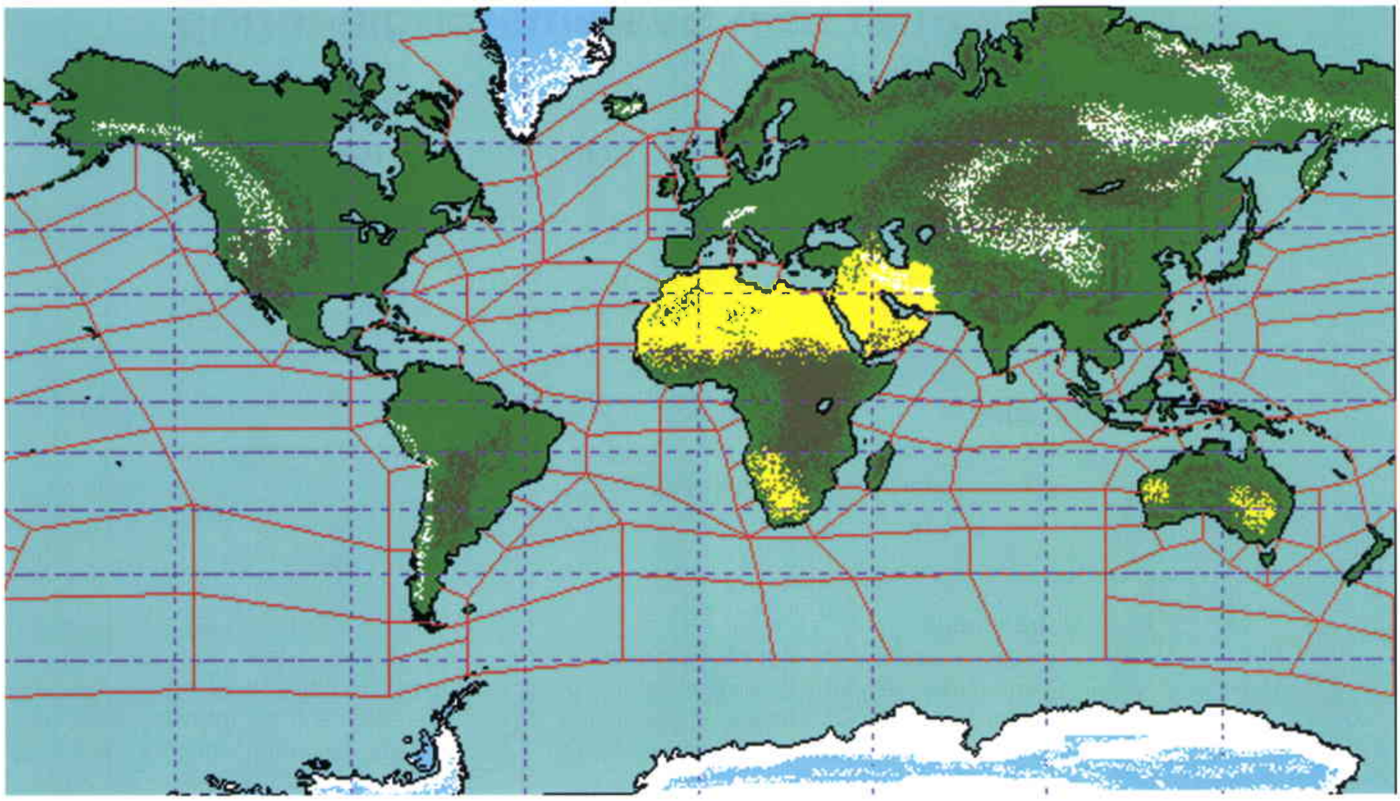

Figure 4b. Carte agrandie des 169 zones de l'Atlas

des produits climatologiques que ceux mis en oeuvre pour l'atlas CLIOSat, mais ne fournit pas des valeurs de paramètres à la côte, ni de paramètres météo-océaniques plus complets comme des spectres directionnels de conditions types ou de tempêtes, au large et à la côte, dont l'élaboration est hors du cadre propre à CLIOSat. Ce service offre donc des produits analogues à ceux de l'atlas CLIOSat à l'exception des valeurs extrêmes de H_S. Pour des zones locales de faible étendue, du fait de l'échantillonnage des données satellitaires, certains événements forts sont susceptibles de ne pas être perçus, ce qui nuirait à la qualité des extrapolations. La constitution d'une base de données locales pour la prédiction des conditions extrêmes sur un site spécifique nécessite donc un enrichissement de la queue de distribution des fortes valeurs de hauteurs significatives à l'aide de reconstitutions de tempêtes calées sur les mesures satellitaires les plus proches. De par son degré d'élaboration, cette procédure opérationnelle ne peut être mise en oeuvre dans des délais compatibles avec ceux d'un service en ligne.

En résumé, le service en ligne permet à l'utilisateur:

— de définir sa propre zone d'intérêt (localisation, taille),
— de choisir ses critères temporels: annuels, trimestriels, mensuels,
— et, soit, de bénéficier de l'expertise d'un spécialiste en météo-océanographie qui analysera ce choix, au vu, notamment, de la cohérence climatologique et de la consistance statistique des résultats escomptés; soit, de laisser les opérateurs du service définir eux-mêmes une aire de cohérence climatologique.

Conclusion

Le service en ligne CLIOSat est opérationnel, et les premiers atlas personnels pour PC ont été livrés en décembre 1995.

On a ainsi pu mettre sur pied, au service des ingénieurs impliqués dans le transport maritime et l'exploitation offshore, une offre en paramètres météo-océaniques, état de mer et vent, qui constitue une révolution par rapport aux moyens disponibles dans un passé encore très récent. Le progrès est particulièrement sensible en ce qui concerne la qualité des données dans les zones où la principale source consistait antérieurement en des observations de navires, et, pour l'exploitation des hydrocarbures, en ce qui concerne le coût et la durée des campagnes d'instrumentation in situ nécessaires à la détermination des paramètres du dimensionnement.

De plus, avec la poursuite des programmes spatiaux d'observation des océans, les bases de données s'accroissent continuellement, renforçant la confiance qu'on peut accorder aux statistiques qui en sont issues. Des méthodes ont été développées, et continuent à l'être, pour étendre leur domaine de validité, spécialement en ce qui concerne les régions côtières et les mers fermées.

The First ESA Systems-Engineering Workshop

– Synthesis and Recommendations

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The First ESA Systems-Engineering Workshop took place at ESTEC on 28 – 30 November 1995. Papers covering major aspects of the systems-engineering domain, and in particular software tools, were presented by participants from the space sector as well as from other industrial sectors. This article endeavours to give something of the flavour of systems engineering and the activities it embraces, as well as providing a synthesis of the ideas and information contained in the presentations and the concluding round-table discussion.

Introduction

The first workshop on systems engineering, attended by over 170 participants and with over 30 papers given, was aimed at bringing together technical managers and systems engineers from the space sector, as well as from a variety of other industrial sectors and international bodies, for the purpose of exchanging knowledge, experiences and views on systems-engineering practices, techniques and informatics tools. A round-table discussion concluded the workshop with participants expressing first synthesis views on the material presented and the general scope and direction of the event.

By organising this workshop, the European Space Agency hoped to identify areas where current systems-engineering practices, in ESA and the space industry as a whole, as well as within other non-space industries, could be improved and made more efficient by the incorporation of lessons learned and state-of-the-art methodologies.

The scope of systems engineering

There are numerous definitions of systems engineering, and whilst they may differ in degree, they mostly emphasise that systems engineering acts across all technical disciplines to integrate and synthesise techniques in support of all phases of a project or programme.

Among the various elements of a typical space mission which must be integrated to support the mission objectives and overall mission concept, the most important are: the space segment, the launch segment, and the ground segment. Clearly then, the application of systems engineering is of interest to a large variety of programmes, all often differing widely in terms of technology, architecture, system development approach, production, nature of users service, overall life-cycle cost, and industrial organisation. An important objective is to achieve economies in carrying out traditional and new space businesses by developing efficient and affordable infrastructures.

As the accompanying panels show, systems engineering within ESA space programmes is thus a broad topic involving many disciplines, including management and technical issues as well as international and intercultural complexities. Today's trends of decreasing governmental funding, fewer projects, and smaller spacecraft make good systems-engineering practice even more difficult and important than it was in the past. In the scientific area, project teams are typically pulled in two opposite directions. Financial constraints, high reliability and schedule obligations require a relatively conservative design approach requiring low-risk strategies. On the other hand, the need to be competitive (indeed to be selected in the first place), the long periods between similar mission opportunities, as well as the desire to optimise scientific return and to remain scientifically relevant, all require an innovative, ambitious and relatively high-risk approach. Effective systems engineering must allow a balancing of these two pressures. In the end, design solutions become increasingly compromised as the margin on instrument resource budgets diminishes. In most cases, it is probably more effective to recognise the need for such compromise at an early stage so as to avoid futile work and unnecessary design features.

Now that cost is not only an issue in almost all projects, but has become a major if not the major design variable, the challenge for space system engineers is even greater than in the past. Thus, the First ESA Systems-Engineering Workshop was expected to help focus the efforts, and aid in the education of present and future space system engineers.

Space systems-engineering issues

The Workshop showed to some extent the status of just what systems engineering is currently considered to be, where it stands in the European space sector at present, and some emerging methodologies and future trends. Although papers were presented on systems engineering in other related disciplines such as the aircraft industry, participation from outside the space sector was limited. Thus, much of what follows is specifically aimed at the space sector, although naturally the comments are still valid for other sectors.

Life-cycles and costs

The basic role of systems engineering is to cover the global aspects of the space system, and more generally the major mission building elements. It therefore covers global system objectives and subsystem interfaces and is concerned with the whole of the project, i.e. from Phase-A (feasibility study) to Phase-E (operational) in the life-cycle.

The mission statement and purpose has changed today. The major task is no longer to make large expensive projects achievable; feasibility is not so important now as affordability and marketability. There has been a fundamental shift on objectives and cost constraints and it is now believed that more investment at the beginning of a project would allow the earlier correction of problems, which would lead to cost savings in the long run.

Systems engineering is a way to bring users, developers and operators together and in fact it must do so in order to be efficiently used in its best sense. In many applications now, it is the end-user who is becoming the driver. Clearly then, in today's systems-engineering process, more emphasis needs to be put on 'end-to-end' engineering, i.e. the process which spans from the user/market demand survey, requirements definition, design and manufacturing to delivery to the user, utilisation and eventually dismantling of the end products.

Representative Examples of Future Space Programme Challenges

- **Navigation**: highly autonomous spacecraft constellations with high-precision orbit determination and time synchronisation.
- **Manned Spaceflight**: habitable modules and crew systems, orbital transfer and reentry means.
- **Space Transportation**: new launcher/transport concepts, air-breathing propulsion (reusable transportation means!), aero-thermodynamics and thermal protection.
- **Space Science**: very large telescopes, exploration of outer planets, ultra-sensitive cryogenic accelerometer and helium thrusters, space interferometry.
- **Space Exploration**: autonomous landing and roving, lunar-night survival, entry thermal protection, airbag landing systems (Mars).
- **Telecommunications**: Mobile and fixed communications using large constellations of autonomous spacecraft, providing broadband voice, sound and data transmission.
- **Earth Observation**: Handling a large variety of remote-sensing data generated by highly sophisticated microwave and optical payloads.

Promising Systems-Engineering Trends Currently Considered by ESA

- **Standardisation**: the reuse of standard units and interfaces across different programmes should be increased.
- **Modularity**: considered essential to allow a platform to be adapted to diverse payloads. It will also facilitate rapid prototyping and the production of standardised building blocks.
- **On-Board Intelligence**: for increasing autonomy and optimising ground activities, especially for the control of satellite constellations; it will cause a continuous escalation in the importance of software.
- **Miniaturisation**: more for the longer term, the advances being made in micro- and nano-technologies should bring benefits in terms of miniaturisation, reliability and mass production to space systems; adaptation to space applications has already begun.
- **Commercialisation**: use of commercial techniques instead of special space methods will capitalise on well-proven developments, including quality commercial components.

Important Cost Drivers

- **Requirements**: over-specification and ineffective task definition are common problems.
- **Model Philosophy**: cumulative cost of different qualification programmes.
- **Use of Test Facilities**: using test facilities should be traded-off against the use of greater design margins.
- **Technology Evolution**: new technologies improve capabilities but inhibit reuse of existing designs and procurement savings.
- **Design Complexity**: affects manpower and development time, and also introduces more uncertainty and risk.
- **Mass/Size**: launcher production and testing costs can be reduced by spacecraft miniaturisation.
- **Schedules**: development and production times can be reduced by new approaches.

However, the end-user or customer has limited money and operates in a competitive situation. There is, therefore, a need for better optimised systems at a substantially reduced cost. There is a clear trend from requirements-driven missions to cost-driven missions, to be completed in less time than in the past. Life-cycle costs should thus be included as a direct part of each mission implementation decision throughout the project life-cycle. Much greater use of far more comprehensive commercial studies must be made to ensure that project teams have better information about the relationships of technical performance and design attributes to cost.

Figure 1. Space systems engineering has to take into account a variety infrastructures to cope with challenging objectives and environments

There should be a full critical review of current practices in project development and systems engineering. Where is the time spent? What is the work flow? How do people think and interact? Functions where systems engineering can help to reduce costs need to be defined. Good systems-engineering practices should enable trade-offs to be made between local alternative system approaches. Cost-effectiveness leads to competitiveness, while collaborating in order to compete is something that companies must learn to do in the present political and economic environment.

Tools and methodologies

During the workshop many papers describing various software tools for systems-engineering activities were presented. From the ensuing discussions, it emerged that it was difficult to understand the precise scope of certain of these tools, the areas where they overlapped with other tools, and the areas for which they were specifically applicable. It was also not clear how these tools could be used in combination, or how much of the investment made on one tool could be reused when moving to another one.

ESA cannot select or impose tools for industry to use. What it could do, however, is to categorise and evaluate tools and provide guidelines for their possible use and advice to the projects and to European industry on selecting the right tools. Thus, information on the appropriate tools, etc. for a given mission should be available even before a project starts. This implies developing standard databases and what is needed also are ways to measure, compare and grade the properties of systems-engineering tools. One possibility is to use *faster, better, cheaper* as criteria for measurement.

Tools should be seen as merely supports for systems-engineering activities, rather than the most important element. Processes such as establishing requirements, funding, interfaces, etc., are more important. It is also believed that tools do not necessarily need to be standardised and optimised – the key is that the various tools should 'talk to each other' and share data through common interfaces. Data in the correct context and configuration and in the right format must be available immediately to everyone wanting to use it at the same time. To this end, the establishment of an ESA-wide Product Data Management System should be considered to provide a common interface to common and historical data.

Regarding the use of informatics tools, it can be observed that most of the current needs are covered by commercial off-the-shelf tools. However, these tools are normally closed (i.e. cannot cooperate with other tools) and therefore the use of different tools along the life-cycle implies starting from scratch because the information stored in them cannot easily be extracted for the benefit of another tool. What is needed is to make the databases these tools are using accessible so that they can be reused by other tools in terms of data and possibly even in terms of functions. Another important comment regarding informatics tools is that they ought to be designed for use by domain experts and not by software specialists.

Real-life systems engineering very often diverges much too much from the planned process, resulting in considerable cost-overruns at various levels. However, the lessons that could be learned from the past are too often simply ignored. No 'corporate memory' tool is really being put into practice so far. Common and historical data plus corporate knowledge must be available, maintained and retained – and be understandable and usable by everyone involved into the mission/system design process at any level.

Tools are fairly well-developed and understood, but methodology is still the weak point. ESA should promote good practice and methods. This implies that they must be established first, or at least formally identified, and laid down in a set of principles. For instance, good systems engineering should minimise developments in architecture, hardware, etc. and thus modularity should be stressed. Systems engineering should also provide cost-reduction incentives. Since hardware typically accounts for only 30% of the cost of a spacecraft, there should be less emphasis on technology as the be-all-and-end-all of everything, and more importance attached to systems engineering.

Synergy with non-space sectors

Although attempts were made to attract papers for the workshop on systems-engineering activities from other sectors such as the automobile, aircraft, military and nuclear industries, few were forthcoming. From the presentations that were made, however, it was apparent that the transfer from space to non-space sectors and vice versa has not been too good and greater interaction is required with other sectors and the European Union.

The military has different priorities, developments, environments and markets. So do other sectors like medical, automobile, shipbuilding, nuclear, railway, aircraft etc. The space sector should try to learn about their markets (political aspects, mass production, rapid prototyping, manufacturing, etc.), as well as their tools and innovative concepts. For example, industry asks for and uses commercial off-the-shelf equipment to save time and to be able to integrate immediately instead of first developing and making new equipment as the space sector does. This is an important lesson for the space sector to grasp.

However, there are opportunities for co-operation between the various sectors. There are several domains of potential cooperation between the defence and civilian space sectors, both of which rely on equivalent systems and related technologies in such areas as:

- earth observation
- telecommunications and positioning
- launching means
- ground control
- test facilities
- data processing.

It is believed that synergy between the civil and military space sectors could foster the avoidance of multiple financing for the development of similar technologies and systems dedicated either to civil or military users, as well as dual-use of facilities.

In addition, space has users in the terrestrial sector (e.g. informatics, aircraft, agriculture, automobiles, etc.) where more cooperation could be fruitful. Furthermore, the design, manufacturing and production processes in the mass-market aircraft and automobile industries should provide some real applications for synergy and emulation.

Relevant systems-engineering concepts for space application

A number of different systems-engineering approaches and concepts were inherent in several of the papers presented during the Workshop. These included taking an

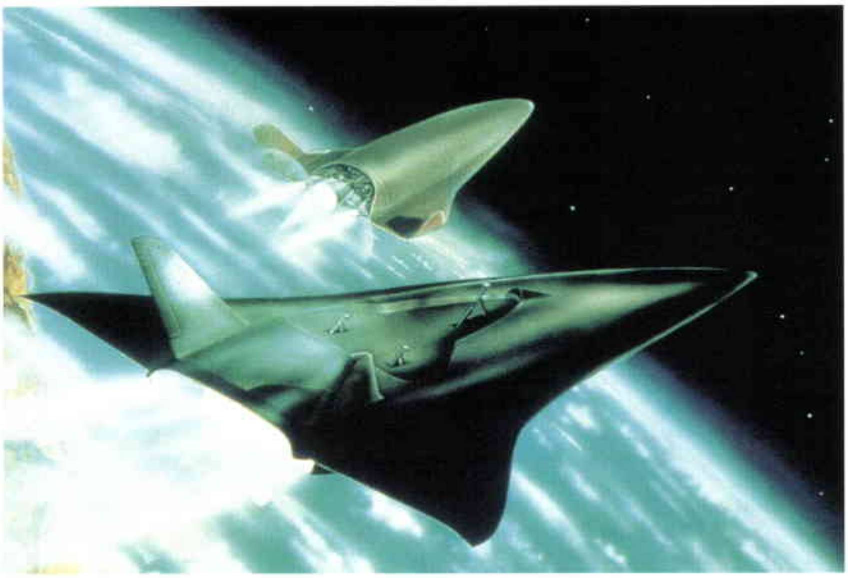

Figure 2. Future space transportation will benefit from synergies with and systems-engineering approaches from other sectors

integrated approach to spacecraft development, the necessity of adequate simulation and modelling, and the requirement for sound education and training for systems engineers.

Integrated development approaches

A number of papers were supporting what can be seen as an 'integrated' approach to spacecraft development, in contrast to the traditionally 'segmented' or strongly 'phase-oriented' approach. A general tendency to want to remove the boundaries between the project phases could be clearly identified. The motivation for this is mainly to reduce overall schedule and costs, which can be achieved through:

- Rationalisation of the schedule by the parallel execution of activities that are traditionally carried out in series.

- Reuse of tools and methods across the development phases. In particular, reuse between development and operations and between analysis and testing need to be promoted, since this is hardly exploited in current projects despite its considerable potential.
- Consideration of operational aspects early in the design process and early prototyping at system level. This provides early verification of interfaces and subsystems, thereby avoiding high costs stemming from late discovery of incompatibilities or non-compliance with requirements.

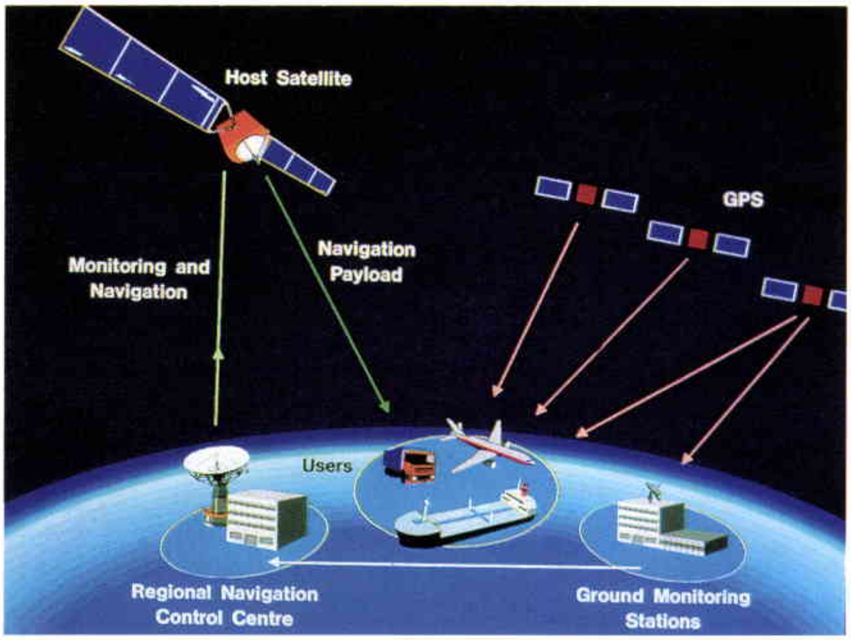

Figure 3. Systems engineering is an end-to-end discipline providing benefits for everyday life

An integrated approach, while minimising overall costs, increases the costs of early phases, which are compensated by later reuse and fewer verification and integration problems.

The problem in implementing the advanced ideas on what could be called an 'integrated development approach' does not seem to be of a technical nature. The basic concept is defined and the tools needed to implement it are mostly available. What needs development is the methodology, which implies that the process of spacecraft development will change radically. In order to implement this methodology, project managers will have to be convinced of its worth and the right culture within industry and ESA will have to be promoted. Clearly, the present concept of geographical return poses a serious difficulty for implementing this approach.

The Prime Contractors presented a number of papers on advanced approaches to different aspects of the spacecraft development process. These approaches did not always reflect the way the companies normally carry out space projects, but rather signalled future trends. For these approaches to become established, a quantification of the benefits and savings compared with a conventional approach is needed.

The proof-of-concept should come from the application of the new approach to a real project. ESA should support the definition of such an approach and its demonstration, in order to reduce the risk for the first application, and disseminate the results obtained. Before doing this, however, the approach should be defined carefully and the necessary tools infrastructure specified and implemented with tools and methods being clearly separated.

Simulation and modelling

Rapid prototyping techniques allow for early verification of mission concepts and subsystem interfaces. This ensures early identification of design problems whose correction is much more costly when discovered later. Also, operational constraints can be taken into account at the beginning of the project to ensure that the design will be compliant with the mission objectives.

Establishing a simulation structure at the beginning of the project to be reused in later phases is driven by the aim of reducing the overall expenditure, i.e. the life-cycle cost, although the costs in the initial phases will increase.

Since in the early stages of new system development, extensive exploration and analysis of design options is a must, it is vital to apply a methodology for performing system design studies centring around a computerised system model containing linked descriptions of each of these components (subsystems) of the complete system. They can be further developed as knowledge about each subsystem deepens. Parametric cost-estimating models should also routinely be included as part of the complete system. Modelling, possibly supported by graphic representation, clearly can help to make system optimisation more straightforward and would also allow for subsystem trade-offs at system level.

Education and training

Emphasis must be placed on the education and training of systems engineers to ensure that they have a broad enough knowledge and skill base to permit them to handle their overall task. The Workshop also showed that a lack of mutual understanding and of commonly agreed terminology are frequently major problems. Thus any efforts to ensure a wider understanding and acceptance of definitions, scope, methodologies and the like are only to be welcomed.

The knowledge and experience that systems engineers acquire during the course of their careers can also be thought of as education and on-the-job training. That knowledge will stay with them and be useful in all kinds of situations, its reuse being an essential element of the overall rationalisation principle. The reuse of knowledge is, however, an area that is lagging behind in terms of tools and practices. There is a clear need to develop knowledge repository systems and associated project procedures to ensure the proper capture and reuse of knowledge (mainly) from the early design phases in the later operational phases.

Conclusions and recommendations

The current trend of reduced government spending on space and the emphasis on smaller spacecraft make good systems-engineering practice increasingly important. Now that cost has become the major design variable, the challenge for space system engineers is even greater than in the past. This first Systems-Engineering Workshop was an attempt to recognise and discuss these trends. Although the contributed papers focused heavily on tools for planning, designing and operating space systems, the Workshop nevertheless provided a good overview of current systems-engineering practices and highlighted the relevant aspects of the overall craft of systems engineers.

There were a number of specific proposals and suggestions made for ESA's consideration which can be translated into specific recommendations:

1. Together with industry, ESA should conduct a full and critical review of current systems-engineering practices in project development. The most important areas where development costs could be reduced should be identified and appropriate life-cycle cost models should be established.
2. ESA should assess the future programmes and prepare for future systems-engineering needs. What are the challenges of the programmes for the next 10 to 15 years, and how can systems-engineering practices be adapted and further optimised?
3. ESA should categorise and evaluate tools and provide guidelines for their possible use, as well as advice to the projects and to European industry on selecting the right tools.
4. A Europe-wide Product Data Management System should be followed, which would provide a standardised interface to both common and other available data.
5. Coupled with the above, ESA should adopt a 'corporate-memory' philosophy and develop a knowledge repository system to ensure proper capture and reuse of knowledge, particularly within projects.
6. Greater emphasis should be placed on the education and training of systems engineers and the potential synergy with applicable practices in other industrial sectors.
7. To enhance the cost/performance benefits of its future space programmes, the European space sector should capitalise on the technology excellence achieved in the various European technology R&D programmes, including autonomy, micro-systems, smart sensors, modelling and simulation and supercomputing developments.

Figure 4. Manned planetary bases will be the ultimate systems-engineering challenge

ESA's Technology R&D Programme could well be a suitable vehicle to trigger these activities.

The success of this first Workshop has underlined the necessity for further ongoing dialogue and exchanges of ideas in systems engineering between the various bodies and companies in the different sectors, not only space. The second Workshop, to be organised in 1997, will concentrate more on the wider issues – as opposed to just tools – and provide greater insight into the processes for developing and implementing cost-effective space missions.

'The Challenge of Change' – A Technology R&D Workshop

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A novel workshop on 'The Challenge of Change', in terms of how to conceive and implement technology research and development, took place at ESTEC on 14/15 February. The reason for this initiative on the part of ESA's Technical Directorate was the growing awareness within Europe that current trends in the space market call for a radical change in the way the Agency, industry and other involved parties work together. One of the pillars of a new future is a strong and healthy Technology Research & Development (TRD) Programme, as the new emerging technologies will determine what can be achieved and at what cost. The prime objective of the Workshop was to arrive at a new policy and set of measures to strengthen the impact of the TRD and to increase the benefits accruing to industry and the national agencies from these efforts.

Scope of the presentations

The Workshop attracted more than 250 attendees from industries both large and small, other space agencies, universities, user bodies and delegations, thereby representing the core of the European space community. The presentations mainly addressed the current problems and potential solutions as perceived by industry and by project leaders. An accompanying exhibition included several commercial products resulting from recent space technology R&D developments.

ESA opened the proceedings with a definition of Technology R&D, an analysis of the current situation for TRD in Europe, and the measures being planned and implemented to face the new challenges. The biggest concerns are the lack of adequate funding and the need to involve industry more closely in R&D decision-making.

ESA also reported on the reforms in progress to improve the strength and effectiveness of its TRD programmes, which fall into three categories:
- innovative TRD
- TRD in support of programmes
- TRD in support of industrial competitiveness.

A new rationale for the Agency's forthcoming TRP Plan which was presented turned out to be very similar to the blueprint for a new TRD planning concept being prepared by Aerospatiale.

European industry, as represented by Eurospace, made a strong call upon ESA to refocus on Technology R&D immediately, and to closely involve industry in the definition and preparation of its TRD activities. Other, non-space examples of successful European TRD programmes were presented such as EUREKA, the secret of its success being seen

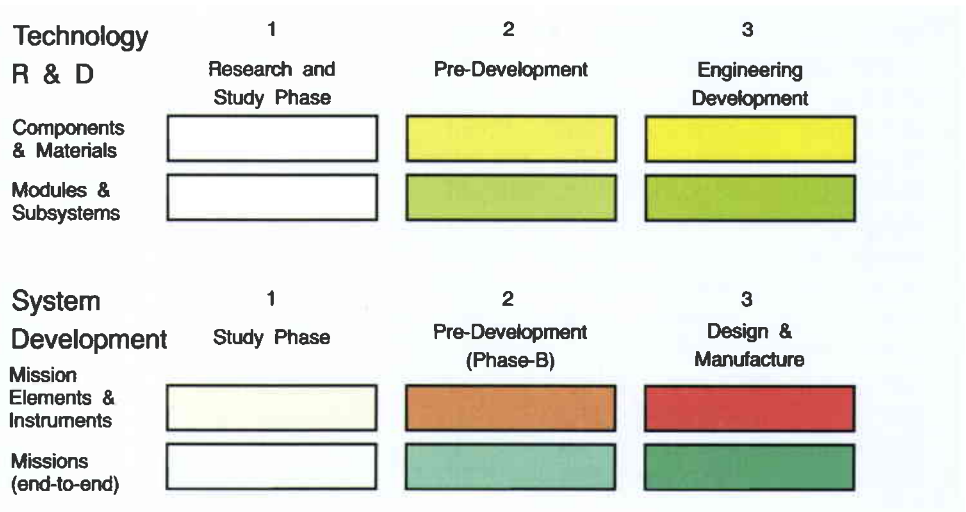


Figure 1. TRD definition and demarcation with system development

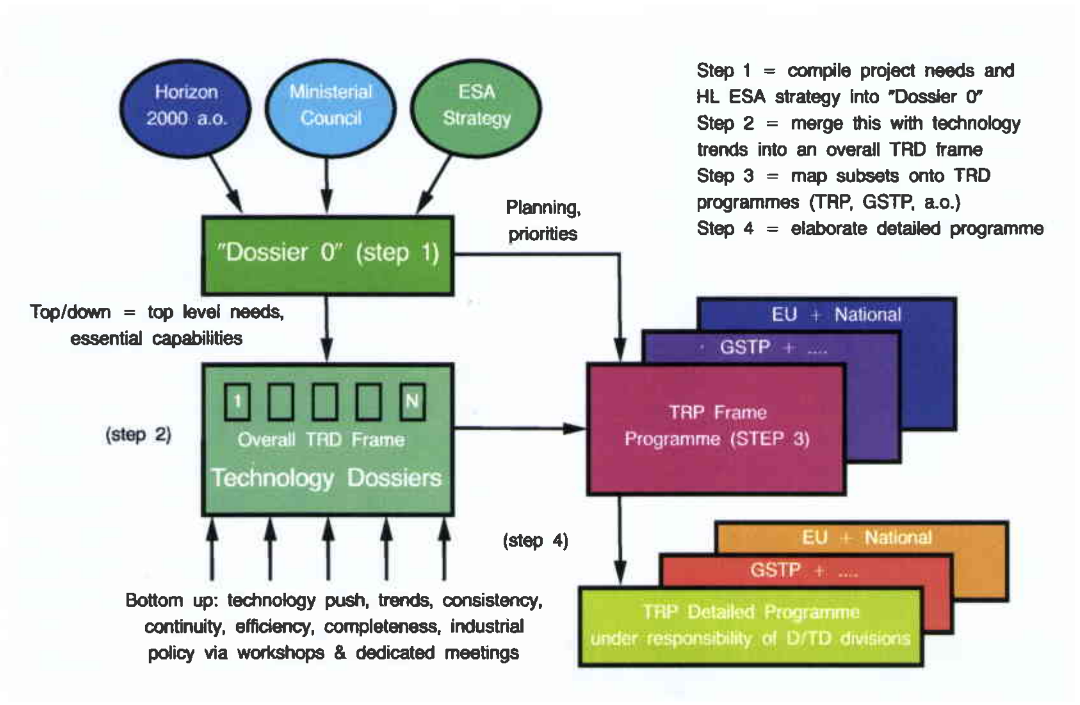


Figure 2. TRD frame programme rationale

as the bottom-up generation of research proposals and a decentralised organisational approach. Industry also took the opportunity to express its views on partnerships with other companies and with ESA, especially in the context of commercial markets.

ESA's Science Directorate underlined the crucial dependency of its projects on the technology programmes and the need to reinforce and speed up TRD efforts, particularly for scientific instruments. Attention was drawn to the fact that, even during their main development phases (Phase-C/D), space projects need access to funding to cover crash TRD actions for the quick solution of the unforeseen technology problems that occasionally emerge at the manufacturing stage.

The representatives of enterprises both large and small emphasised the vital role of TRD for their particular companies, not least for the preservation of critical skills. Many interesting views were presented on how a TRD programme comes about, as an intelligent mixture of technology-push and market-pull. Above all, industry is concerned with market-orientation: TRD must create value, be in line with a business plan, start very early, proceed up to full technology-readiness to enable a short time-to-market, and take the constraints of the final design (e.g. cost-effectiveness) into account from the outset.

The chairman of the Central Technology Advisory Committee (CTAC) presented valuable 'lessons learned' from past successes and failures, mainly in the defence area, showing the need for long-term budget stability to enable continuity. He also stressed that not only large aerospace companies, but especially small industries (subcontractors and equipment manufacturers) should be supported by ESA.

Participants from the academic world introduced their latest views on TRD management and strong emphasis was given to the creation of partnerships with complementary TRD organisations. The classical management structures (hierarchy, matrix) were challenged and the application of focussed, task-force management was advocated. The need to invest a little in university work and in the next generation of space professionals was stressed as an indispensable element for a healthy future.

Figure 3. The TRD exhibition

Key issues

Globalisation, synergy and partnership

The space community, especially in Europe, is too inward-oriented with regard to space technologies, to ESA projects and to local markets. This has to change dramatically: the real growth takes place outside ESA in the commercial markets, where non-space technologies and companies have a lot to contribute (synergy, spin-in and spin-off), and the only market is the global market. The technology needs go far beyond ESA's resources, so that partnerships with other TRD organisations need to be established. A questionnaire distributed to Workshop participants to solicit the opinions of the various stakeholders on crucial issues clearly revealed that all want ESA to play a central coordinating role in this respect.

Figure 4. The Workshop in progress

Shortage of TRD funds, and implementation

There was unanimous agreement that the current level of TRD within ESA is largely insufficient to safeguard the future of Europe's space activities, and a level of 8% of the ESA overall budget was judged vital to meet the future challenges. There is a danger of over-prioritisation, and even of the abandonment of certain core R&D activities if the current funding shortage cannot be resolved. Moreover, as far as the actual implementation of these TRD efforts is concerned, only a small minority of the Workshop attendees supported the current ESA TRD programme structure, with a mandatory element (TRP) and many optional Supporting Technology Programmes (STPs).

Differentiation of TRD activities

Most participants believe that the innovation effort needed to support industrial competitiveness in commercial markets differs so much in nature from innovative TRD for long-term applications that a clear differentiation must be made, with separate implementing rules.

ESA has in fact already committed itself to categorising all TRD activities into three major classes, as noted earlier.

Involvement of industry in TRD planning

There was a clear consensus that industry needs to be involved in the process of defining the TRD activities and priorities. The participants' preference was for an ESA-defined 'frame programme' for the innovative TRD and TRD support to programmes. As far as TRD support to industrial competitiveness is concerned, however, the 'bottom up' alternative (industry makes proposals, ESA screens) was judged to be the best. A clear, institutional mechanism is needed to make this happen, as even regular workshops of the current type would not be sufficient to enable closer involvement of industry in the day-to-day work.

Co-funding by industry

This was clearly identified as one of the possibilities for increasing the level of TRD funding, but under very strict conditions. Private funding for space developments can only be raised for existing and very-near-term markets, and agreements must be reached on a case-by-case basis. Public funding is fundamental all along the value chain, and remains the only option for long-term applications, even for those with eventual commercial potential.

Technology readiness, market orientation, speed

The mood of the Workshop was clearly driven by commercial market considerations, but even non-commercial applications require these three characteristics. Fokker Space showed that a great deal of the emphasis in technology TRD has shifted dramatically in recent years from one-off design to serial products, from top performance to price/performance, from functional requirements to cost requirements, from non-recurring cost to recurring cost. Two of the key factors in terms of market success are time-to-market, and technology-readiness. Both need to be integral parts of any modern R&D strategy.

All in all, however, the consensus of the Workshop participants on how best to meet 'The Challenge of Change' was a preference for step-by-step, evolutionary innovation, rather than quantum-leap revolution, but based on a coherent European policy.

RENDEZVOUS WITH THE NEW MILLENNIUM

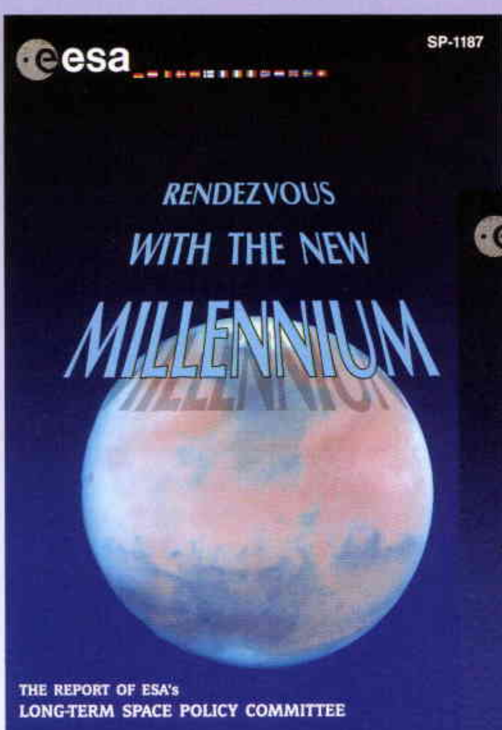
The Report of ESA's Long-Term Space Policy Committee

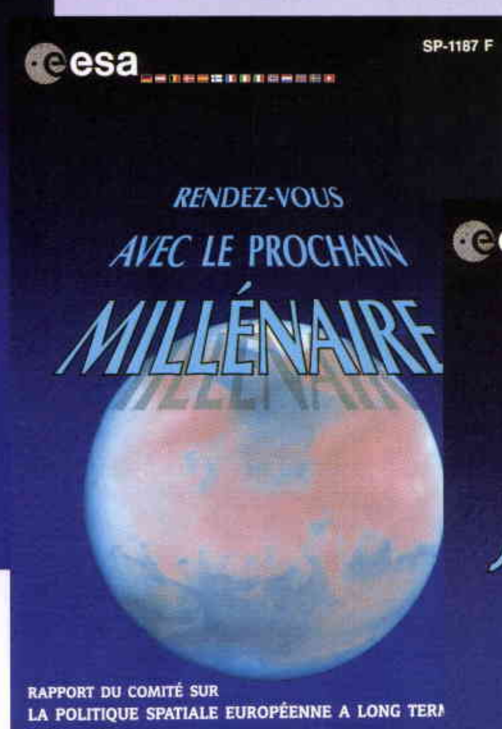
With 30 years of space activities behind us, we can now look forward to the next millennium on far more solid ground than the early pioneers ... At present, most space activities go from study phase to launch in about 10 years. The near-future is therefore already accounted for, and the major options for the next 20 years are also known. But what about the decades beyond that, and how will the world change over the next 50 years?

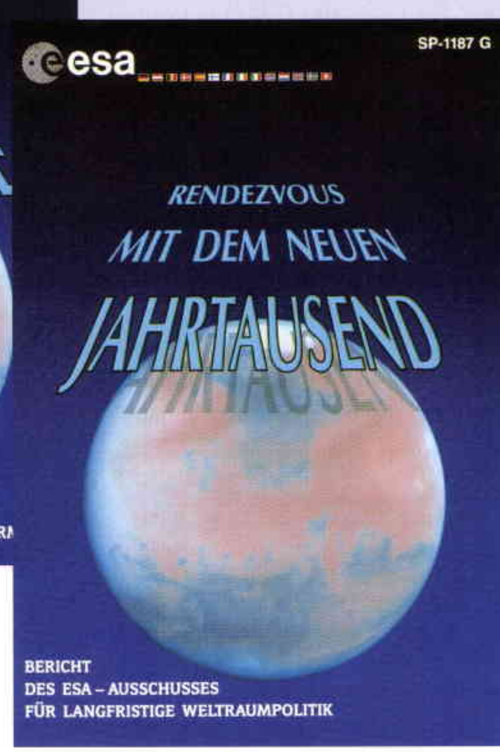
To identify a strategic vision for European space activities in the next century — one that will respond both to the challenges and threats facing humanity in the future — the ESA Council created a Long-Term Space Policy Committee (LSPC) in June 1993. The Commitee's task was to prepare a report on European space policy after the year 2000.

The LSPC chose to take a 50-year perspective in order to go beyond the mere extrapolation of current trends while still keeping in mind the present technological and financial constraints. The Committee analysed in depth the themes that it deemed to be of importance and collected the thoughts of recognised experts in relevant domains.

Its work has culminated in this report, *Rendezvous with the New Millennium*, which was presented to the ESA Council Meeting at Ministerial Level in Toulouse in October. The Ministers welcomed and endorsed the report: they expressed their satisfaction with the perspectives taken and have invited the Committee to continue to reflect on the long-term space policy for Europe.







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The Transponder — A Key Element in ESA Spacecraft TTC Systems

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Introduction

Telemetry, Tracking and Command (TTC) are vital functions of a spacecraft. They allow data to be communicated between the ground and the spacecraft for spacecraft control and command. The communication is through a telecommunication link established between the control station on the ground and the satellite. The TTC transponder on the spacecraft plays the role of radio frequency interface with the ground.

The Telemetry, Tracking and Command (TTC) system and, more specifically, the transponder form an essential part of most spacecraft. Current transponders, which were developed in the 1980s, are being updated to provide improvements in all areas — cost, flexibility, power consumption, mass and size. ESA is developing a number of standard models to meet the needs of future missions. For near-Earth missions, there are several concepts, depending on the method of communication and the size of the user: for satellites using direct to ground communication, the Compact Standard Transponder (CST) is being developed, while for those using a data-relay satellite, the Small User Transponder (SUT) is being developed for smaller users, and the Dual-Mode TTC Transponder (DMT) for larger users. For deep space missions, a Deep Space Transponder (DST) is envisaged.

Virtually all spacecraft — and certainly all ESA spacecraft — are equipped with TTC transponders. It has been recognised since the early days of spacecraft development that all spacecraft require such a type of control from ground, and standards for TTC interfaces between spacecraft and ground are well established. ESA and other space agencies, including NASA, DLR, CNES, and NASDA, have collaborated in their definition in order to ensure compatibility for efficient use and cost-effective cross-support.

With the TTC transponder now a standard feature of almost all ESA and European national programmes, ESA has a function dedicated to the design and development of TTC transponders: the RF Systems Division of the Technical Directorate. After in-depth surveys of future needs expressed by ESA's Programme Directorates, studies and developments are performed in the frame of the technology programmes of the Technical Directorate (the Technological Research Programme, and General Support Technology Programme), or of the Programme Directorates (the Advanced Systems Technology Programme). The objective is to design equipment that will be reusable for the maximum number of spacecraft with the minimum recurring cost. However, the great variety of spacecraft developed under the Agency's programmes does not allow for the definition of a single, unique and universal TTC transponder.

Importance of TTC to a mission

It is essential that a reliable communication link between the ground station and the spacecraft is maintained throughout the satellite's different phases of operation.

During the Launch and Early Orbit Phase (LEOP), ground control sends the required mission commands, such as to fire the booster rockets for orbital correction, to deploy the antenna or solar array, or to fire the apogee boost motors. Some of these operations must happen at precise times, while others can take place during a window of time.

During the lifetime of the mission, which is generally four to ten years, the satellite receives daily the commands required to reconfigure functions according to requirements at the time. Earth observation satellites, such as SPOT or ERS, receive instructions for their next orbits, such as the region of interest of the Earth to observe, the direction of view, or the spectral band to use. A data-relay satellite, such as Artemis or DRS, receives daily commands to inform it of its low Earth orbiting clients; it receives the necessary data for pointing one or more of its antennas towards that satellite and following its path while data relay communication is required.

The three functions of telecommand, tracking and commanding are also essential.

The telecommand link is used to upload commands to the spacecraft, particularly when mission characteristics are not defined until after launch. The Giotto probe, for example, having successfully encountered Halley's Comet and being surprisingly only slightly damaged despite several collisions with cometry debris, could be deployed for another mission, to encounter a second comet, Grigg-Skjellerup. Giotto's flight plan was completely redefined while the satellite was in orbit and the reconfigured data was then telecommanded from ground.

Telecommanding is of particular importance to deep-space probes. Their distance from the Earth creates communication problems (although the probes have a high degree of autonomy to overcome those problems). Firstly, the signals reaching the probe from the ground are so weak that the amount of data that can be transmitted is limited. Secondly, it can take up to several hours for the radio signal from Earth to reach the probe if the probe is at the edge of the solar system, which makes controlling the probe extremely difficult.

The telemetry link is equally important to the success of a satellite mission. Telemetry is the data received from the spacecraft, generally about the status of its systems. For scientific satellites, including deep-space probes, the telemetry link also carries payload data. During launch and early orbit, telemetry allows ground technicians to check that commands are being carried out correctly, e.g. that boosters are being fired or that the antennas or solar panels are being deployed. Throughout the mission, it enables the mission control centre to survey the 'insides' of the satellite, its configuration, its status, and in the case of failure, it provides the basis for the decisions that have to be made.

TTC's third function is tracking and ranging. The transponder demodulates the ranging signal contained in the uplink and remodulates it onto the downlink. Thus, by measuring the return propagation time, the distance between the ground station and the satellite can be estimated. Moreover, the transponder has the ability to generate a downlink carrier phase coherent with the uplink carrier, allowing precise estimations of orbit and speed from measurements of Doppler offset and rate of the downlink frequency at the ground station.

TTC for ESA spacecraft

The architecture of a typical satellite TTC system is shown in Figure 1. The system comprises two low gain antennas with hemispherical coverage, two transponders each with transmitter and receiver, and two command decoders. The interface with the rest of the satellite is via the On-Board Data Handling (OBDH) system.

The uplink carrier with the telecommand (TC) signal from the ground station is received by one of the low gain antennas and applied to both receiver inputs via the diplexer. The signal consists of a 2 GHz carrier, phase-modulated by an 8 kHz or 16 kHz subcarrier, itself BPSK-modulated by the TC data at a rate of less than 10 kbit/s. The two receivers work in 'hot redundancy' and output the modulated subcarrier at baseband to the active decoder. The decoder recovers the TC data and sends it to the OBDH.

The active transmitter generates a downlink carrier phase and frequency coherent with the uplink carrier, which allows measurement of Doppler by the ground station, aiding satellite

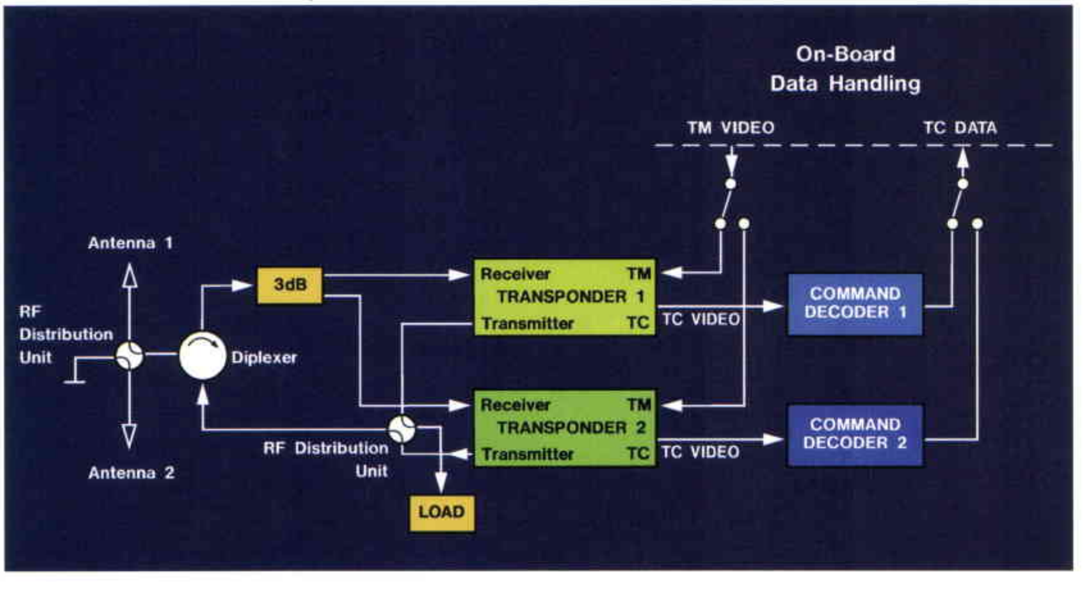


Figure 1. Architecture of a typical satellite TTC system

localisation. The uplink signal also contains the ranging signal which is demodulated by the receiver and transmitted back to the ground with the telemetry (TM), using phase modulation on a single downlink carrier. The transmitter amplifies the modulated downlink signal (in the 5 W RF power range according to mission requirements) which is connected to the selected antenna via the diplexer and RF switches.

The TTC system must be operational during all mission phases even if attitude control is lost, thus the antenna system coverage must be as near as possible to omnidirectional. The hemispherical coverage antennas have low gain (LGA). If the mission requires higher data rates (for the same transmit RF power), a directional High Gain Antenna (HGA) is necessary. In this case, the LGAs are used only during LEOP and in an emergency (e.g. loss of attitude control) for TTC housekeeping data, and the HGA is used during the operational phase for high-rate transmission of payload data as well as for normal TTC communication.

The transmit and receive signals use the same antenna but they are isolated from one another by the diplexer. The receive signal is applied to the two 'hot redundant' receivers. 'Hot redundancy' minimises interruption of control in emergencies and increases reliability by avoiding power on/off cycles of the receivers. The transmitters are switchable; the selection of the transmit signal is made via the RF Distribution Unit (RFDU). This switching capability together with the redundant architecture allows a 'crossed' scheme where the transmitter of one transponder can be used with the receiver of the other. This scheme has already been implemented on several ESA satellites.

The internal architecture of a TTC transponder is shown in Figure 2.

Regulatory aspects and standardisation

The question of frequency bands is of fundamental importance to telecommunications systems. The use of the frequency spectrum for RF transmission by all telecommunication systems is highly regulated by the International Telecommunication Union (ITU) in Geneva and is subject to formal registration and approval by the ITU authorities. The telecommunication agencies of 145 signatory countries meet at regular intervals to discuss and decide the allocation of the frequency spectrum to the different agencies. The space agencies are usually in a minority and must dedicate much effort to defend their interests.

Until the 1970s, most satellites' TTC was performed through VHF links (130 MHz bands). This was the case for ESA's OTS satellite for instance. Since the early 1980s, all European satellites, with the exception of some commercial communication satellites and some minisatellites, use the S-band (2 GHz) for their TTC (see inset). Deep-space probes such as Ulysses and Giotto may also transmit their telemetry in the X-band (8 GHz), to be able to transmit data at a high rate and to help in the evaluation of errors on ranging measurements through the ionosphere.

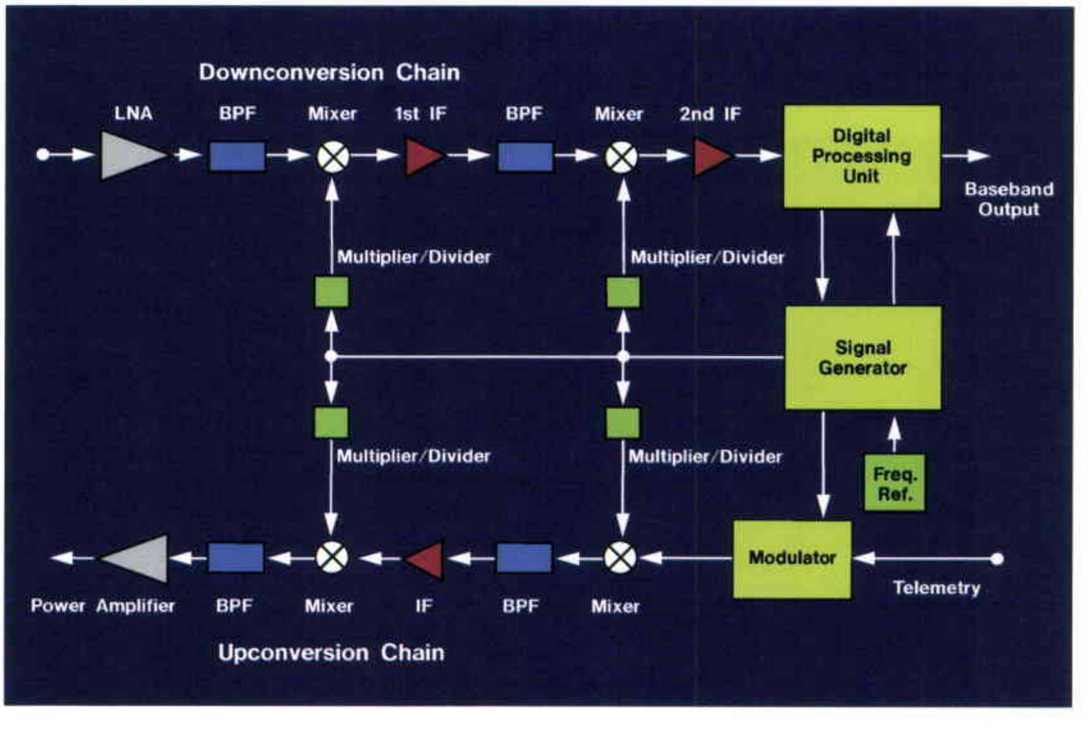


Figure 2. Block diagram of a typical TTC transponder. It comprises:

- **a receive chain which tracks the uplink telecommand signal received from ground, demodulates the command data (TC) and forwards this to the onboard data handling unit (OBDH). It also demodulates the ranging signal (RNG) which is then fed to the input of the transmitter for retransmission to ground**
- **a transmit chain which modulates the telemetry data (TM) and ranging signal onto the downlink carrier.**

With the growing number of satellites, the frequency band allocated for space applications in the S-band is becoming increasingly crowded. Therefore, in the future, near-Earth missions could use the X-band, with further investment in the ground segment being required. In addition, the increasing needs of deep-space missions in terms of the amount of data to be transmitted is leading towards the general use of the X-band for such missions. Extending to the Ka-band (30 GHz) is also under consideration for some missions.

In order to protect the scarce resources of allocated frequency spectra, space agencies have had to cooperate with each other and coordinate their efforts in order to present a unified position at the ITU. This is done, for instance, through committees such as the Space Frequencies Coordination Group (SFCG), in which ESA is an active member. This need for cooperation plus the high cost of developing and maintaining a ground network has led the major space agencies to achieve a high degree of compatibility for TTC matters.

This compatibility has been developed, for a large part, in the frame of the Consultative Committee for Space Data Systems (CCSDS), which recommends TTC system designs. Thanks to this work, a satellite from a given agency can be supported by most stations from most other agencies.

This compatibility proves to be very practical. For example:

— After separation from the launch vehicle, several ground stations are used to assure the coverage of the LEOP operations. Support from another agency's stations is often called upon.
— In February 1990, NASA's Deep Space Network's 70 m antenna in Madrid was used to reactivate ESA's Giotto satellite. The compatibility of the TTC equipment and the high level of standardisation made the operation possible.
— ESA's SOHO and Cluster spacecraft operations will be extensively supported by NASA stations.

TTC is therefore a truly worldwide standard.

System constraints and transponder types
The type of mission being undertaken has a significant impact on the constraints and requirements imposed on the design of the TTC transponder. Communicating with a spacecraft in geostationary orbit is different from communicating with an interplanetary probe.

In practice, with respect to TTC transponders, there are three different types of space applications:

— *Deep space*
According to the ITU, deep-space missions are those in which the spacecraft's distance from the Earth is greater than 2 million kilometres. As far as the transponder is concerned, the main constraint for these missions is the low received power due to the distance the signal must travel. This dictates that such transponders must be capable of very low data transmission rates, of a few bits per second in some instances. Additionally, coding schemes may be used for error detection and correction.

Selection of a Frequency Band

The frequency band used by the TTC system is dictated by the propagation, performance and regulatory requirements.

The majority of TTC systems use the S-band (around 2 GHz), which allows minimal propagation loss through the Earth's atmosphere (less than 1 dB) and data rates up to approximately 1 Mbit/s. This is usually quite adequate for Earth-orbiting missions (up to and including GEO). Deep space missions require higher frequency bands to achieve the increased performance resulting from higher antenna gain for a given size.

Non-scientific satellites sometimes use a different band for their payload. For example, commercial telecommunications satellites (usually in GEO) operate at the C-band (around 6 GHz) or Ku-band (around 14 GHz) for their payload. During the Launch and Early Orbit Phase (LEOP), they may operate their TTC in the S-band. Once they enter the operational phase, they use their payload band for TTC. Meteorological satellites (also usually in GEO) normally use the L-band (around 1.5 GHz) for their payload; their TTC however uses the S-band both in LEOP and during the operational phase. Other smaller users, such as universities, tend to use the S-band for their TTC systems.

— *Near Earth*
As opposed to deep-space missions, near-Earth missions are those in which the satellite is less than 2 million kilometres from the Earth. This includes missions to the Moon.

Generally, the absolute power is not a concern in these missions, but some of them have a highly eccentric orbit which, for the transponder, means that the signals received from the ground station when the satellite is at apogee have a low level while the signal that the transponder receives when the satellite is at perigee is proportionately considerably higher. The transponder (Fig. 3) therefore has to be able to cope with a dynamic range in the received signal that can be as high as 70 dB.

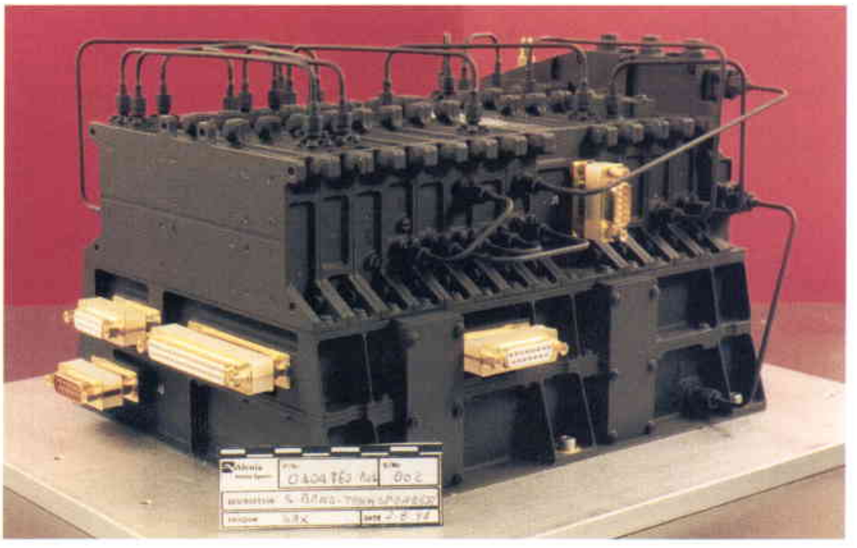


Figure 3. Standard S-band transponders (Photos: Alenia Spazio and Alcatel Espacio)

In addition, the Doppler effects (frequency shift and frequency rate of change) when the satellite approaches perigee can be extremely high, which constitutes a further constraint for the receiver which must track these frequency dynamics.

— *Low Earth Orbit and transmission via data relay satellites*
Finally, the third class of application is satellites in low Earth orbit (LEO) that transmit their TTC signals either directly to ground or via a Data Relay Satellite (DRS). The DRS concept is shown in Figure 4a.

The problem for missions using DRS is that the distance between the data relay satellite and the LEO satellite is similar to the distance between the data relay satellite and the Earth (Fig. 4b). Data relay satellites are not free to radiate a large amount of power at the Earth's surface because it might cause interference to terrestrial users. (This power limitation is clearly defined by the ITU in terms of maximum power spectral density per unit surface). However, the power received by the transponder on the LEO spacecraft has to be high enough for reliable communication.

The solution is the use of a technique called spread spectrum, whereby the signal transmitted by the data relay satellite is spread over a large bandwidth so as to reduce the radiated power per unit bandwidth. It appears as noise to any other user and hence does not generate interference. However, a suitable TTC transponder with a spread spectrum demodulator can interpret the signal correctly. This feature implies an additional complexity for the design of transponders for this type of application.

Transponder as a scientific instrument for deep space

The ground-station tracking system has a dual purpose for deep space missions. The first function, as discussed earlier, is the provision and reception of RF carriers used for telemetry and command functions. Secondly, the radio tracking system also performs radiometric functions in which information is obtained on spacecraft position, the radio propagation medium, and hence some properties of the solar system. This information is essential for spacecraft navigation but also provides an important contribution to the scientific return of deep space missions.

A coherent link from the ground-station to the spacecraft and back to Earth can be used to observe a variety of scientific phenonema:

— Mass and gravity fields of planets and their satellites
The motion of a spacecraft through the solar system is determined by the gravitational field it encounters. This motion can be discerned through Doppler, ranging and VLBI measurements (Fig. 5), so the transponder becomes a test probe for the gravity fields through which the spacecraft travels.

— Atmospheric composition
The intensity characteristics of the radio signal passing through an atmosphere provide valuable information on the atmosphere's absorption or scattering properties of its vapours, cloud condensates or primary atmospheric constituents. Two areas can be investigated: the atmosphere of the Earth, or more interestingly for deep space missions during planetary occultation, the constituents of other atmospheres.

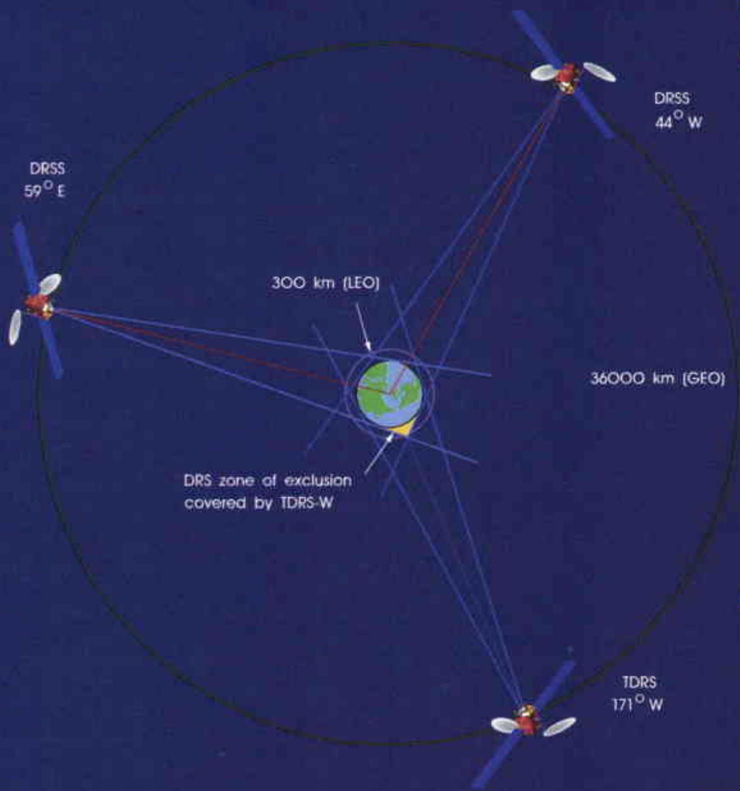
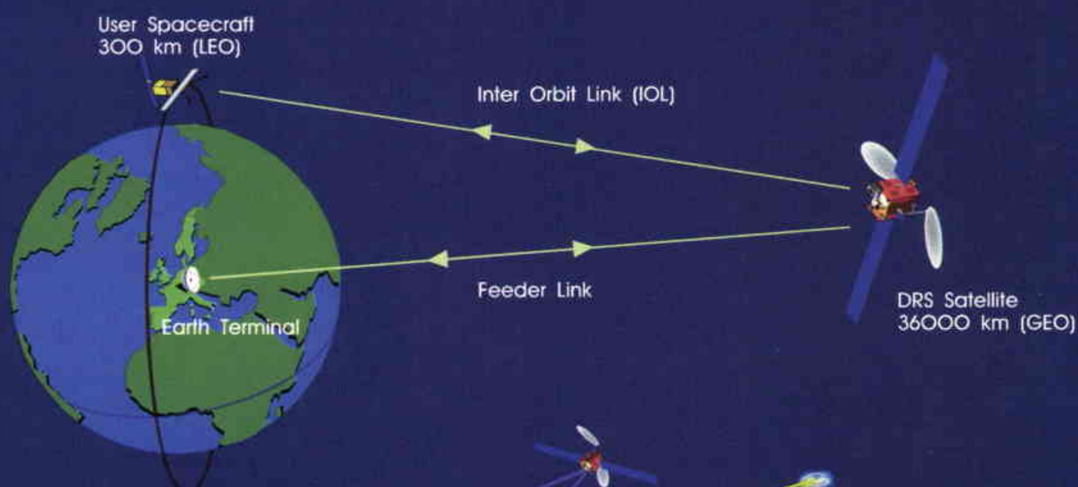


Figure 4. The concept behind data relay satellites

a. Traditionally, communications are made directly between the satellite and the Earth. As a result, contact time is limited to the periods when the spacecraft is visible from the ground station.

The concept of Data Relay Satellites (DRS) which provide the communication link was introduced some years ago. The system comprises a geostationary satellite fixed in relation to an observer on the ground, providing a relay between the user in low-Earth orbit and the ground. This concept considerably increases the radio contact time: three relay satellites carefully positioned in GEO provide 100% coverage of possible low-Earth orbits (with the exception of polar regions). The current generation of Data Relay Satellites (DRS) is not regenerative, in that the signals received by the DRS are not demodulated, but only amplified, filtered and frequency-shifted to the required frequency before re-transmission.

b. This type of system implies two types of bidirectional link: the link between the ground station and the DRS, i.e. the feeder link, and the link between the DRS and the user satellite, i.e. the Inter-Orbit Link (IOL). The telecommand signals transmitted from ground towards the DRS on the feeder link are retransmitted by the DRS towards the user satellite. The telemetry signals transmitted by the user satellite work similarly in the opposite direction.



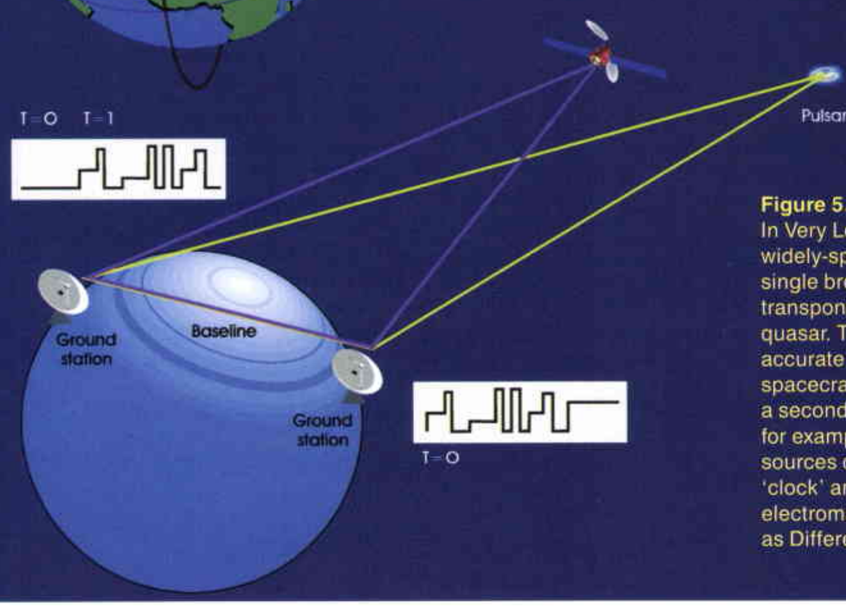


Figure 5. Locating spacecraft using VLBI
In Very Long Baseline Interferometry (VLBI), two widely-spaced antennas on the Earth observe a single broad-band source, for example, a spacecraft transponder transmitting widely spaced tones or a quasar. The received signals are correlated with an accurate time reference, allowing the location of the spacecraft to be calculated. If, further to this, there is a second source angularly close to the spacecraft, for example a quasar with a known location, several sources of error can be reduced, in particular the 'clock' and the media through which the electromagnetic wave travels. This method is known as Differential One-way Ranging (delta-DOR).

— Ionosphere, solar corona and interplanetary medium
The change in group and phase velocity of radio waves in a tenuous plasma depends on the density of electrons in the plasma and inversely on the square of the frequency of the wave. If the transponder is transmitting two distinct carrier frequencies and the distance is known, the electron density can be derived from the different changes to the two waves. Over time, a density distribution of plasma can be obtained.

Technology evolution in TTC transponders

Transponders in the 1980s

The more demanding requirements of ESA missions in the 1980s necessitated a move from the VHF band (140 MHz) to the S-band (2 GHz). Phase modulation was used, which allowed onboard coherent demodulation of the received signal. This approach permitted the development of a line of 'standard transponders' suited to any type of Earth orbit as well as for deep space applications. The companies Thomson-CSF of France (later renamed Alcatel Espace) and Selenia Spazio of Italy (later renamed Alenia Spazio) began producing flight models of the transponders around 1981-82. The transponders have been used successfully for such ESA programmes as ERS, ISO, SOHO, Meteosat (MOP), Ulysses, Giotto, Eureca, and Hipparcos.

The technology used in the transponders is primarily analogue, and the architecture of the receiver phase lock loop is 'long loop', where the Doppler frequency error is compensated progressively at each stage of the down-conversion chain. The downlink carrier is phase coherent with the uplink carrier, allowing two-way Doppler measurement. The ranging signal transmitted from ground is received by the transponder and transmitted back to ground. The traditional long-loop transponder contains many analogue components requiring time-consuming and costly tuning. It is also large and inflexible.

Transponders today

As with all spaceborne equipment, there are demands to reduce mass, size, power consumption and cost. In order to achieve such gains, there has been a steady replacement of old technologies where appropriate and a move from analogue towards digital technology. Progress has been made in miniaturisation (MMIC, ASIC), and digitisation of the demodulation, modulation and frequency generation functions. As well as the gain due to cost and size reduction, digitisation reduces the requirement for tuning, gives better repeatability of performances, and when a microprocessor is included, gives added flexibility.

Some recently launched satellites have begun to incorporate the digital technology. ERS-2, for example, contains two transponders of different generations: one is an analogue transponder of the type developed in the early 1980s, and the other is semi-digital in that it implements digitally some of the demodulation functions.

In response to the requirements of the Columbus and Hermes programmes, which were to use data relay systems, a new type of transponder was designed, one that could communicate with ground in two ways, either directly using traditional phase modulation or via a data relay satellite using spread-spectrum PSK modulation with suppressed carrier. From the breadboard of that so-called dual-mode transponder, two models have been derived and will fly in the near future:

- the Dual Mode TTC transponder (DMT); Figure 6 shows a digital receiver module of the DMT
- the Experimental S-Band Terminal (ESBT), which will fly aboard SPOT-4 (Fig. 7).

Such spread-spectrum transponders offer extensive programmability in areas such as carrier frequency, choice of PN spreading code, and data rate.

Transponders of the future

Those spread-spectrum transponders, however, are too large and costly for many small spacecraft users who would like to use data relay systems but are limited in budget and do not need the flexibility of previous spread-spectrum transponders.

To meet those reduced requirements, ESA is developing a Small User Transponder (SUT). The lower mass and recurring cost expected for this transponder align with the expected growth in smaller satellites requiring DRS support.

There is a similar requirement for direct-to-ground applications. The majority of users, who are in fact in GEO or LEO, require smaller and cheaper transponders but with a similar performance. In response, the Compact Standard Transponder (CST) is currently under development. It will use improvements in technology as well as a simplification of the equipment functionality to produce a compact, lightweight and low-cost solution. The idea for the CST came from the comparison of the high cost and complexity of its predecessors (all

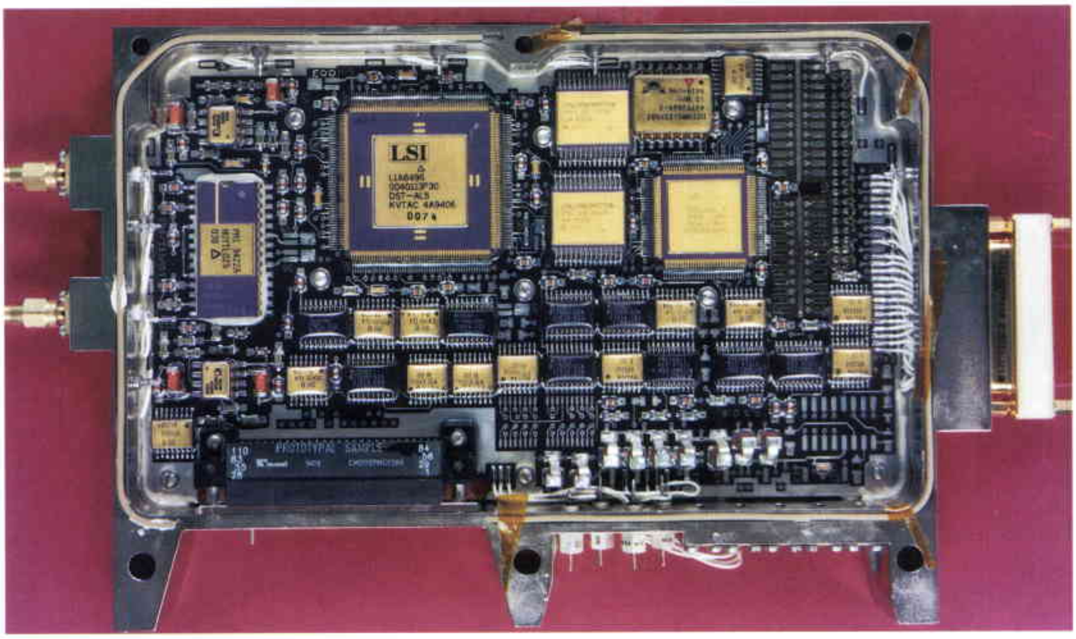


Figure 6. Digital receiver module of the Dual Mode Transponder (DMT) used for the Huygens mission (Photo: Alenia Spazio)

analogue transponders used in ESA missions since the 1980s) with the commercial transponders used in telecom satellites. This complexity is partly due to the need to operate up to 2 million kilometres from Earth versus the 40 thousand kilometres for commercial transponders.

The design study for the CST will run under ESA's Technological Research Programme (TRP) during 1996, and an engineering model is planned to be developed under the General Support Technology Programme (GSTP-2) beginning in 1997.

For deep space, there would be a clear advantage, either for reasons of telemetry capacity, necessity of antenna size reduction, increased navigation accuracy or for ionospheric delay resolution, for several of the planned future ESA missions to use the X-band or the Ka-band. In particular, Mercury, Rosetta, Intermarsnet or the Moon missions would be able to take advantage of the higher frequency bands. The Ka-band has a unique advantage for missions such as Mercury as it suffers negligible signal-to-noise degradation due to signal scintillation in the solar plasma.

An engineering model of such a Deep Space Transponder (DST) (see inset) is envisaged under the GSTP programme to ensure Europe keeps a deep space transponder capability for future ESA missions.

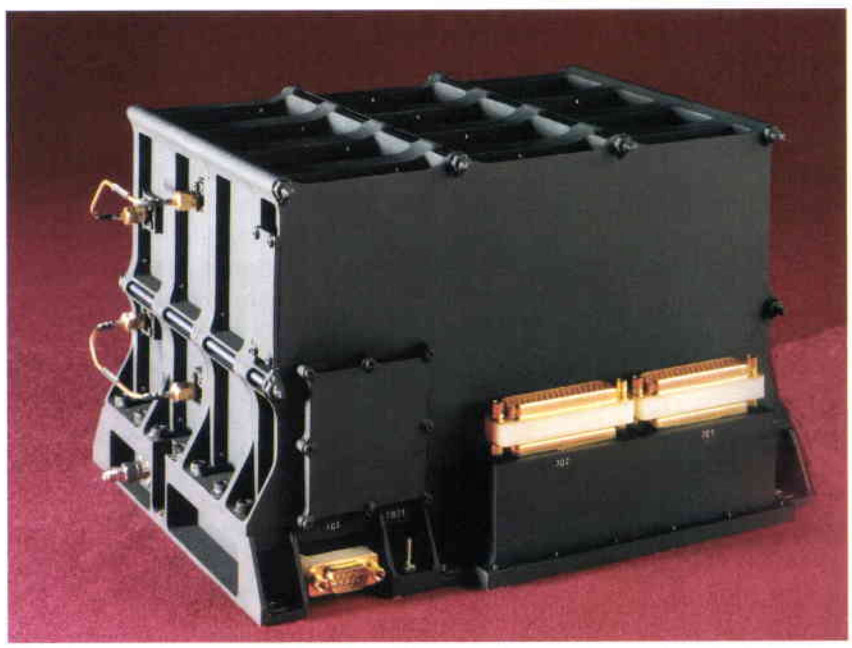


Figure 7. An Experimental S-Band Transponder (ESBT) (Photo: Alcatel Espace)

Essential Features of a Deep Space Transponder (currently under development)

X-band uplink
X-band and Ka-band downlink (coherent)
VLBI moderator
Low noise figure
Low acquisition and tracking thresholds at high Doppler rates
Highly modular digital design
Programmable

ESA's Guidelines for Spacecraft Structures

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Structures and Mechanisms Division, ESTEC, Noordwijk, The Netherlands

J. Wilson
RJ Technical Consultants, Charente Maritime, France

ESA's series of structural handbooks provide guidelines to aid in the design process of a flight article, from the conceptual stage through to its qualification. They also provide a central reference source to accumulated project and research and development experience. Activities currently underway to ensure that the books keep pace with the fast evolving knowledge of space structures are also described.

The role and evolution of the handbooks

In space applications, the term 'structure' effectively relates to load-bearing components or those with a high mechanical stiffness. Such components may range from the mechanical constituents of a launcher to the parts of a spacecraft antenna dish.

ESA Publication No.	Full Title	Current Issue
ESA PSS-03-203†	Structural Materials Handbook: • Volume 1: Polymer Composites. • Volume 2: New Advanced Materials	Issue 1 (Feb. 1994) Issue 1 Rev.1 (Apr. 1995): • Revised Chapters: 20, 28, 38 & 40 • New Chapters: 95 to 97 'Soft Materials'
ESA PSS-03-204‡	Structural Acoustics Design Manual	Issue 1(in press 1996)
ESA PSS-03-207	Guidelines for carbon and other advanced fibre prepreg procurement specifications	Issue 1 (Dec. 1990)
ESA PSS-03-208	Guidelines for threaded fasteners	Issue 1 (Dec. 1989)
ESA PSS-03-210	Adhesive Bonding Handbook for advanced structural materials	Issue 2 (Mar. 1995)
ESA PSS-03-212	Aide Memoire on structural materials and space engineering	Issue 1 (Mar. 1995)
ESA PSS-03-1202	Insert Design Handbook	Issue 1 Rev.1 (Sept. 1990)

† Replaces ESA PSS-03-1101
‡ To replace ESA PSS-03-1201 Issue 1 (Oct. 1987)

Figure 1. ESA's handbooks and guidelines for structural engineering

Realising the design of the structure usually involves a process of evolution and iteration in order to achieve the required mass goal and produce a cost-effective product. This involves, from the outset, careful consideration of the purpose and function of the structure in question, as well as of the induced loads and environmental features associated with the mission. These, in turn, influence the choice of the material and the construction format that will be used. In addition, the knowledge base related to the material, the advocated joining techniques, the manufacturing process, and the verification and product assurance tasks must be considered. As the design development and verification programme evolves, the engineer requires progressively more detailed information. The more he can rely on existing experience and information, gained through other, similar projects, the easier the task should be.

ESA has developed a series of Structural Handbooks and Guidelines over the years, to help fulfil such requirements for information (Fig. 1); each handbook brings together the accumulated project and R&D experience into a single source book. The handbooks are intended to ease the interface between design, manufacture and test requirements by highlighting typically important development features. A further aim is to facilitate information exchange within the space community as a means of harmonising approaches to common or similar structural engineering problems. Additionally, research institutes and similar establishments can use them to maintain an awareness of the general state of the art in this field.

At a time when the industry has undergone a period of recession and regrouping, the handbooks also represent an accumulation of knowledge that might otherwise be lost, or require extensive time and effort devoted in costly research to rediscover it.

The information contained within the guidelines is based on many sources, which include:

- project and more general aerospace experience, drawing attention to commonly accepted design, development, manufacture and test tools
- other recognised handbooks
- product assurance publications
- results emanating from ESA studies
- synthesis of the proceedings of ESA and other international conferences
- technical publications
- information provided by specialist engineers.

The collection of such information is not without its difficulties. The size and complexity of space projects means that, whilst important information exists and is documented, it may not be readily accessible. The proprietary nature of part of the information may cause additional complications. If such information is deemed commercially important, access will be carefully controlled. However, much has become available in the interest of enhancing a common knowledge base for the sometimes highly specific needs of the space industry as a whole.

The responsibility for retrieving and synthesising such information has been entrusted in part to ERA Technology (UK) and RJ Technical Consultants (France). Specialists at ESTEC and within industry also participate, depending on the topics of interest. For example, DASA (Bremen, Germany) has contributed extensive information on composites and insert technology; British Aerospace (Bristol, UK) has been largely responsible for the dissemination of information on joints with threaded fasteners; and both British Aerospace and the Institute of Sound and Vibration Research (Southampton University, UK) pioneered the manual on structural acoustics.

The documents are reviewed by an ESA-sponsored Advanced Structural Materials Information Exchange Group (ASMIEG) and by ESTEC staff specialising in materials and structures. The ASMIEG was formed in 1981 and meets three or four times a year. Each ESA member state is entitled to representation. From time to time, the group is supported by other specialists from industry.

Complementary role of guidelines and standards

Standards and specifications are generally created in response to a specified need. Unfortunately, in many instances they may have grown independently as national standards, or may even reflect an individual company's needs based on commercial requirements.

It is evident that harmonising standards on a European basis is a challenging task. The case of the historical development of composites, with the inherent anisotropy of such materials as a key factor, is a good example. Their extensive use is accompanied by differing in-house test standards. It is clear that those test standards as practised by companies have often been influenced by commercial requirements. Material portfolios, manufacturing capabilities and techniques, structural design experience, historical data bases and cost of testing all have their influence.

Cooperative programmes appear to be the main incentive for developing common standards as a means of reducing costs and aiding technical collaboration. Compared with programmes the size of Airbus Industrie, for example, it remains to be seen if space programmes are of sufficient commercial longevity to ensure success without additional support. Nevertheless, the handbooks bring together information that 'points-up' any identified need. Continual monitoring of 'who is doing what and how and for what reason', as undertaken for the handbooks, helps to keep such matters in perspective.

The handbooks and the issues affecting them

As research and development continue to provide new information, the handbooks must also evolve. They are continuously being reviewed and updated. The following is a summary of the status of each book and a discussion of some of the issues affecting the topic or the work now being undertaken in that area.

Aide Memoire on Structural Materials and Space Engineering

The most recent addition to the series is the Aide Memoire on Structural Materials and Space Engineering (ESA PSS-03-212). It brings together in one document all the factors that designers of space structures must evaluate (Fig. 2). It provides basic information on the use of metals and fibre-reinforced composite materials within the whole design development process. The emphasis is on materials in current use or intended for future project applications but some consideration is given to emerging high-temperature materials. The handbook cannot, for reasons of useable

ESA PSS-03-212: Aide Memoire on Structural Materials and Space Engineering

Structural Design Development
Concept Design
Detail Design
Specific Requirements
Design Analysis & Testing
Production Engineering
Manufacture
In-service Appendices:
- Design documents & Verification Tool Listing
- ESA PSS document Listing
- Test Specification Listing
- Nondestructive testing techniques

Glossary & Index

Figure 2. Basic contents of the Aide Memoire on Structural Materials and Space Engineering (PSS-03-212)

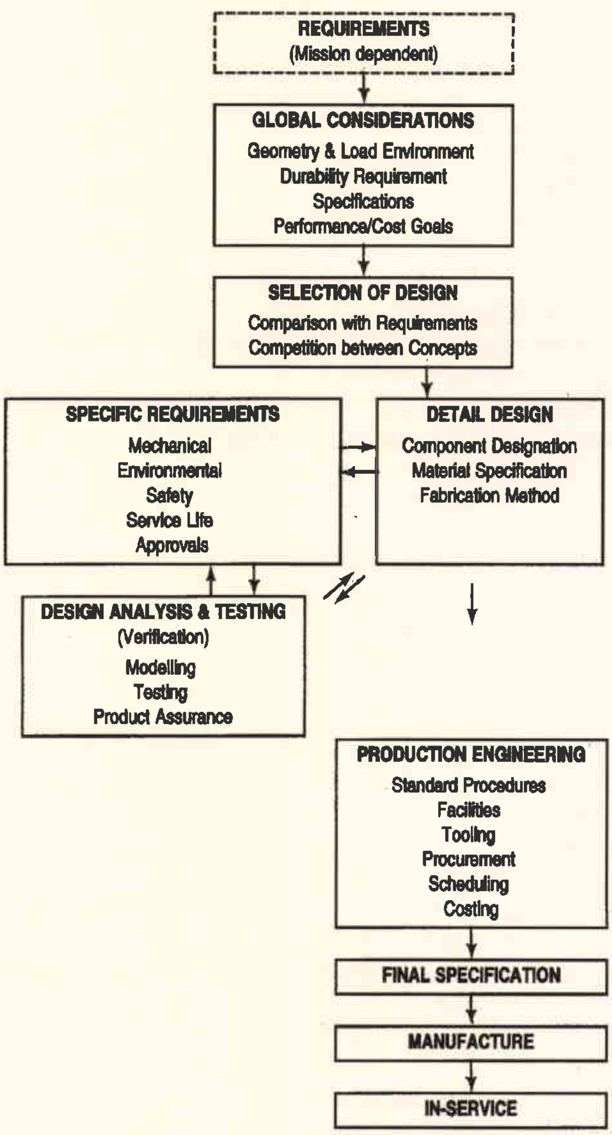


Figure 3. The design-development process for ESA space projects

size, present a detailed analysis of each topic. However, a comprehensive referencing system directs the reader to source documents, design guides, other manuals and ESA PSS documents, and verification tools including recognised test specifications and non-destructive techniques.

Given that project requirements vary with each mission, the first chapter provides an overview of the design-development process for ESA space projects (Fig. 3). Using a systems approach, it describes how the structure is part of the overall project and how the various subsystems interface with each other. The terminology and typical project phases used within the rest of the handbook are defined and illustrated by example. The remaining chapters are organised into 'factors to be considered' at each stage of the project, from concept through to, in some cases, the recovery, refurbishment and re-use of structures.

Structural Materials Handbook

The Structural Materials Handbook (ESA PSS-03-203) has been enlarged from the original, only polymer-based composites design handbook (now incorporated into Volume 1) to contain information on metal- and ceramic-based materials, non-polymer composites, coatings, smart materials and textiles (Volume 2). All aspects of their technology and actual or potential uses in space structures are described (Fig. 4).

A revision to the handbook, expected to be issued in 1996, will reflect the growing interest in cyanate ester systems in the field of reinforced plastics. This interest is due, in part, to the need to replace older, discontinued epoxy systems together with the better resistance of cyanate esters to moisture take-up and possibly microcracking.

An investigation, involving five European companies, examined eight cyanate ester or epoxy Ultra High Modulus (UHM) Carbon Fibre Reinforced Plastic (CFRP) systems. In some cases, excellent resistance to micro-cracking was exhibited. The study did not reject any system on the basis of its susceptibility to microcracking. However, the study did demonstrate that 'prepreg' acceptance for space use is determined by a number of parameters, including: availability of specific fibre/resin combinations; confidence in prepreg supply; satisfaction of procurement acceptance criteria; and production of good-quality laminates by optimised processing conditions.

ESA PSS-03-203: The Structural Materials Handbook

Subject Matters covered in Current Issue	Draft Revision Completed in 1995	Previewed for Revision in 1996
VOLUME 1: Polymer Composites		
Material Properties & Applications	← Properties & Test Methods	
Design Calculation Methods		
General Design Aspects		← Orbit Environment
Load Transfer & Design of Joints		
Design of Structures	← Filament Winding	
Integrity Control	← Inspection	
Verification Guidelines		
Manufacturing, including:		
Economics & Repairs		
Glossary & Index		
VOLUME 2: New Advanced Materials		
New Advanced Materials		
Advanced Metallic Materials		
Advanced Ceramic Materials, including:		
Ceramic-, Glass-, Carbon-Carbon		
General Design Aspects		
Load Transfer & Design of Joints		← Joining metals, including welding
Fracture & Material Modelling		
Case Studies & Design		
Integrity Control & Inspection		← Brittle materials: damage tolerance
Thermal & Environmental Integrity		
Manufacturing Aspects, including:		← Metal forming
Techniques & Expertise		
In-Orbit Control & Health Monitoring, including:		← Smart technology for space
Smart technologies		
Soft Materials, including:		
Textiles - testing and applications		
Appendices		
Glossary & Index		

Figure 4. Basic contents of the Structural Materials Handbook (PSS-03-203)

The handbook will also incoporate recent improvements to information on non-destructive testing.

A survey of mechanical test methods for composites as used by industry has demonstrated the strong historical allegiances to specific test methods. However these differ in detail between organisations. Often, their material data bases are built up by consistently using the same method and retaining confidence in the results. There is also evidence to indicate that results from mechanical tests can be operator-dependent, giving further inconsistencies when comparing results from different organisations. In fact, different organisations can place different emphases on the expectations placed on the test methods. Test-method selection criteria will include: comparison of different materials, generation of design data, quality control procedures, damage tolerance investigations and collaborative data exchange.

ESA PSS-03-207:
Guideline for Carbon and Other Advanced Fibre Prepreg Procurement

Description & Classification of Prepreg, including:
- Fibre & resin type, thermoplastic matrix

Prepreg Requirements for Qualification & Batch Testing, including:
- Specification,
- Identification & Marking
- Release documentation & packaging
- Prepreg construction
- Prepreg quality & defects
- Batch acceptance (Supplier)
- Incoming inspection (User)

Laminate Requirements, including:
- Minimum properties
- Cure schedule
- Manufacturing factors
- Testing - batch, incoming & qualification

Test Methods

Figure 5. Basic contents of the Prepreg Procurement Guideline (PSS-03-207)

Such a scenario presents a somewhat daunting prospect in terms of any attempts to impose common standards. However, the section on this topic is being extensively updated to place the situation in proper perspective and to provide clear guidelines on all aspects of the the test methods.

Other intentions are to include information on hot structures as developed for the Hermes programme and more general information from Ariane-5 developments.

Guidelines for Carbon and Other Advanced Fibre Prepreg Procurement Specifications

The Prepreg Procurement Guideline (ESA PSS-03-207) is intended as a general guide for organisations preparing specifications for the procurement of particular thermo-setting resin impregnated reinforcing fibre systems (prepreg) (Fig. 5). These are primarily epoxy-,

Figure 6. Basic contents of the Adhesive Bonding Handbook (PSS-03-210)

ESA PSS-03-210
Adhesive Bonding Handbook

Materials, including:
- Adherends
- Adhesive types & properties

Design, including:
- Joint selection, theory & practices

Manufacturing, including:
- Surface preparation
- Bonding methods & QA aspects

Test & Inspection

Bonded Repairs

Case Studies:
- Bonded connections
- Bonded structural materials

Appendix
- Test methods & standards

Index

bismaleimide-, polyimide- and cyanate ester-matrix based materials. Many of the features also relate to thermoplastic-matrix prepregs. The parameters that may be necessary to control and/or monitor for qualification and batch control of a prepreg are described.

Adhesive Bonding Handbook
The Adhesive Bonding Handbook (ESA PSS-03-210) has recently been updated and reissued (Fig. 6). It now contains new and extended information on adhesives suited for space and factors influencing the successful design and manufacture of bonded joints, both as an assembly technique and used in repair. Bonding in sandwich panel construction is also described. Test and inspection methods are covered, along with application examples in the form of case studies.

Figure 7. Contents of the current Insert Design Handbook (PSS-03-1202), and topics under revision

ESA PSS-03-1202
Insert Design Handbook

Current issue		Revision in 1995/96
Design, including types of: inserts, sandwich, potting, arrangement.	←	Design aspects for composite faceskins
Insert capabilities, including: strength, edge influences, fatigue.	←	Potting procedures & controls
Insert Manufacturing	←	Comparison of analysis & testing
Testing	←	Case studies: Use of inserts in major projects (Ariane 4 & SPOT equipment bays, UMS, SILEX)
Quality Assurance		
Appendices: Analytical determination; Insert standards		

Insert Design Handbook
The wide use of sandwich panels, normally with a honeycomb core, in load-bearing space structures has meant that a reliable method is required to join them together and attach other items. Inserts are used for this purpose. The Insert Design Handbook (ESA PSS-03-1202) is currently under revision to expand the content to include the need for information on subjects highlighted in a comprehensive industry study conducted in 1995. It is intended to include a simplified mathematical design approach, test-prediction corroboration studies for real space structures and a section on the design approach for composite-skinned sandwich panels rather than the metal-skinned variety (Fig. 7).

Guidelines for Threaded Fasteners
Threaded fasteners are frequently used for assembling structural components. The Guidelines for Threaded Fasteners (ESA PSS-03-206) provides detailed descriptions of joint design using threaded fasteners, calculation steps and worked examples. It also provides guidance on preloading methods, embedding and relaxation, fatigue and fracture mechanics, allowable lubrication for space use, and other issues.

Further studies, including friction effects and vibration loosening, have produced information that will be included in a revision (Fig. 8).

Assessments of under-the-head and thread friction components of the torque tension relationship are not well established. After earlier development problems, a satisfactory load cell has now been produced and a 'ruggedised' version will be used to provide data this year. For some critical joints, differences between friction conditions can lead to preloading problems. For example, when the bolt is tightened from the head, when underhead friction is high, insufficient preload in the bolt can result. Conversely, if underhead friction is too low, too high a preload can result and failure of the bolt can ensue, particularly in such materials as titanium.

Work investigating the effect of reusing fasteners is ongoing using the same load cell facilities. The facility does in fact offer assessments of different bolt configurations, not previously available to stress engineers.

DASA and NLR have recently completed a detailed study into the damage tolerance characteristics of threaded fasteners including non-destructive testing techniques. A synopsis of this work will be included in the next release of the Guideline.

Structural Acoustics Design Manual
A new issue of the Structural Acoustics Design Manual (ESA PSS-03-204) will be released in 1996 (Fig. 9). The previous version focussed on the use of statistical energy analysis (SEA) for the treatment of acoustically-induced equipment vibration problems. Both the reverberant sound field used to simulate the payload launch environment and most classes of structures at frequencies above around 150 Hz have a high modal density. It is therefore necessary to treat the dynamical systems involved on the basis of statistical populations having known distributions of their dynamical parameters. The vibratory energy is the primary variable of interest. The more familiar parameters, such as pressure and acceleration, can be derived from considerations of this energy of vibration.

In conjunction with the new handbook, the associated software program has been reissued, as GENSTEP 3, and includes a PC version. It can now also treat the transmission of high frequency vibrations due to local 'point' loadings as required, in particular, for microvibration analysis.

The new issue has also been extended to incorporate reference to other prediction tools such as finite element (FEM) and boundary elements together with design aids for simpler models using classical modal analysis. This facilitates the examination of the individual modes and their behaviour. It may be needed at frequency regimes of low structural modal density and where SEA does not apply.

Details of a means of predicting noise reduction for cylinders using classical modal interaction analysis in conjunction with the program 'Proxmode' are also included. This has been used successfully for initial estimations of Ariane fairing internal noise prior to the production of large-finite element models.

Another cause for concern is the generally acknowledged gap in the frequency range covered by FEM (low) and SEA (high). Alternative means of predicting the response behaviours for both mechanical and acoustic excitation are the subject of current investigation by both MATRA and ISVR. The manual will be updated accordingly.

Work is continuing on improving both vibration-level predictions for platform-mounted equipment and their representation in unit-level tests. At the moment, projects rely heavily on tools based solely on statistical syntheses of past test data.

Work on Artemis, Polar Platform, Olympus and other programmes has highlighted the importance of microvibrations as a source of unwanted 'jitter' for sensitive payloads. The prediction tools used at high frequencies relate closely to those used for structural acoustics investigations and the representation of the structural elements is the same. Work is ongoing to augment the existing manual with design information that has been

ESA PSS-03-210
Guidelines for Threaded Fasteners

Current Issue		Draft Revision Completed		Future Revision
Definition of Joint Categories	←	Slip coefficients	←	Reuse of fasteners
Static Loading				
Dynamic Loading	←	Vibration loosening		
Embedding & Relaxation			←	Review of calculation methods
Fatigue & Fracture Mechanics				
Preloading	←	Residual torsion		
Corrosion				
Lubricants for Space	←	Separated friction torques		
Joint Validation by Testing				
Manufacturing & Quality Control Aspects				

Figure 8. Contents of Guidelines for Threaded Fasteners (PSS-03-210), and topics under revision

Figure 9. Contents of the Structural Acoustics Design Manual (PSS-03-204), and topics under revision

ESA PSS-03-204
Structural Acoustics Design Manual

Previous Issue		Subjects in New 1996 Issue		Future Revision
Introduction Prediction Procedure	←	Use of Finite Element Analysis & Boundary Element Methods.	←	Frequency 'gap' between FEM (low) & SEA (high).
Structural Response Sound Transmission Input Power	←	Modal analysis treatments: Joint acceptance formulae for different excitation fields & simple structural elements.	←	Improved methods of vibration prediction for platform mounted equipment boxes.
Loss Factors	←	Revision of SEA prediction program to GENSTEP3.		
Test Procedures Extrapolation Procedure	←	Extensive information on zoning & scaling.	←	Microvibrations
Test Specifications	←	SEA related testing methods & experimentally determined parameters.	←	Habitation acoustics.
Artificial Damping Annex 1: GENSTEP2 Theory	←	Transmission loss program PROXMODE for cylinders (modal interaction method).		

gleaned from investigations to date, which is quite extensive.

Longer term plans include the incorporation of information on design aspects for habitation acoustics which relate to onboard generation of noise and its transmission via air circulating ducts, for example. Means of noise estimation and methods for passive and active means of noise control will be incorporated.

Concluding remarks

The series of ESA handbooks are a vehicle to promote information exchange across the European space community. Each handbook represents a single-source of accummulated knowledge directly appropriate to space projects, which may be otherwise difficult and time consuming to locate. They are a valuable resource by providing extensive information and guidelines to aid structural space engineering. They are appropriate to a readership of many disciplines working on space projects, and their role is complementary to that of standards and specifications.

As space structures continue to evolve, so will the handbooks, thus assuring accessibility to state-of-the-art information for the space community.

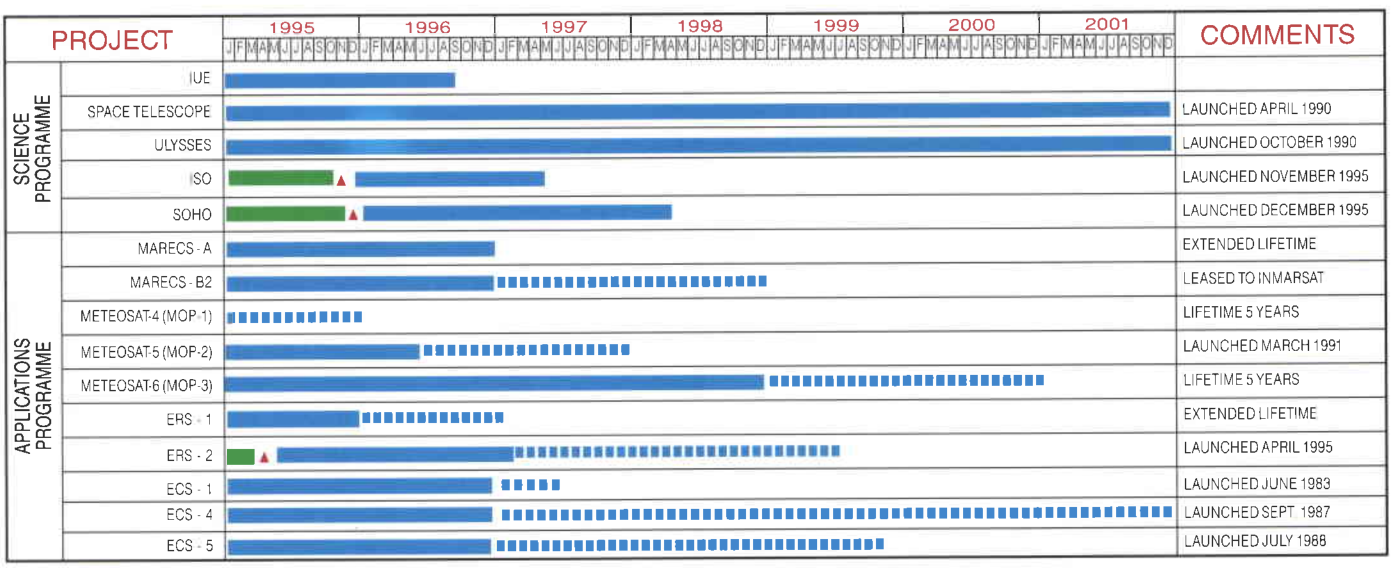
Acknowledgements

Thanks are due to many people for their continued support and for providing valuable contributions to the various handbooks: the members of ASMIEG, David Bashford of ERA Technology Ltd, Jorg Bolz of DASA, David Light of British Aerospace, and Neil Pinder of ISVR Consultancy Services (Southampton University, UK).

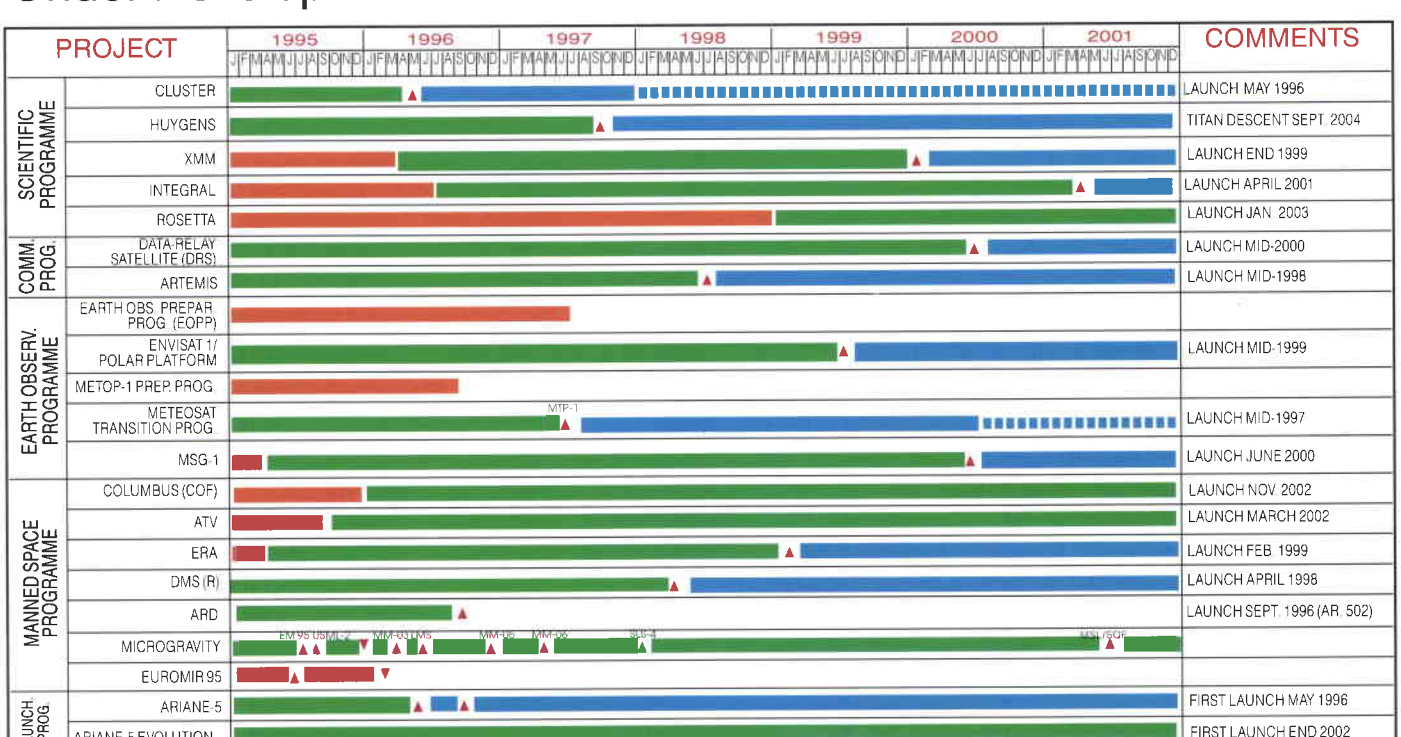
The Guidelines and Manuals described here can be obtained, at a nominal charge, from ESA Publications Division. See Order Form etc. inside back cover of this issue for further details.

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

SOHO

Une étape importante a été franchie mi-février lors de la mise en orbite en halo du véhicule spatial SOHO. La série d'essais de recette ayant suivi la manoeuvre d'injection a confirmé les excellentes performances du véhicule spatial.

Une première campagne scientifique coordonnée de petite échelle a déjà été mise en place. Des observations seront donc réalisées simultanément par les instruments de SOHO et ceux du satellite solaire japonais Yohkoh, ainsi que par des observatoires au sol. Les particularités spécifiques du Soleil explorées lors de cette campagne furent les panaches polaires du trou coronal sud.

A la mi-mars ont été achevés les préparatifs des deux modifications à apporter au logiciel de bord afin d'accroître la robustesse de certaines caractéristiques du système, dont la régulation d'orientation et la correction d'orbite. A la suite d'essais au sol approfondis réalisés par des simulateurs de l'ESA, de la NASA et des industriels, ces corrections ont pu être téléchargées et testées sur le véhicule spatial en orbite.

ERS-2

Le satellite ERS-2 a fêté son premier anniversaire en orbite le 21 avril 1996. L'exploitation en tandem d'ERS-1 et d'ERS-2 fournit toujours des images interférométriques exceptionnelles de la surface des terres au moyen de l'instrument SAR (radar à synthèse d'ouverture).

La recette en orbite du diffusiomètre d'ERS-2 sera bientôt achevée et la pleine capacité opérationnelle est prévue pour mi-mai 1996.

L'exploitation en tandem a permis de réaliser un double étalonnage précis entre les instruments RA d'ERS-2 et d'ERS-1. L'exploitation complète des données jumelées des deux instruments au cours de la phase géodésique a permis d'établir un géoïde océanique d'une résolution sans précédent.

L'expérience de surveillance de l'ozone à l'échelle du globe (GOME) témoigne d'un fonctionnement stable en orbite. Le système complexe de traitement au sol est toujours en cours d'optimisation, les produits obtenus avec les données des instruments étant comparés avec ceux des stations de validation au sol. La mise sur le marché des produits de GOME devrait commencer en avril 1996.

Le fonctionnement de l'IRR (radiomètre infrarouge) de l'ATSR-2 a été interrompu fin 1995 à cause d'une anomalie du mécanisme de balayage du radiomètre. A la suite d'une série d'essais en orbite de brève durée qui avait pour but de diagnostiquer ces anomalies et de remettre l'IRR en état de marche, le fonctionnement du mécanisme de balayage s'est considérablement amélioré. Le travail de l'IRR devrait donc reprendre en avril 1996; on continuera néanmois de suivre de près les données en orbite et d'analyser attentivement cette anomalie.

Les données du PRARE d'ERS-2 sont maintenant considérées opérationnelles, même si la mise en place de l'ensemble des stations au sol n'est pas encore achevée.

Le fonctionnement des véhicules spatiaux ERS-1 et ERS-2 demeure stable et le prochain événement majeur sera le cinquième anniversaire d'ERS-1 le 17 juillet 1996.

Cluster

Les quatre satellites ont été alimentés en ergols et l'intégration du matériel thermique en est actuellement à sa phase finale sur le site de lancement de Kourou. Le conditionnement des batteries a démarré, et l'intégration et les derniers travaux relatifs au matériel thermique commenceront après Pâques. Les quatre véhicules seront préparés en vue de leur lancement le 30 mai sur le premier vol d'Ariane-5 (V501).

La revue d'aptitude au vol de la mission (MFRR), tenue à l'ESTEC début mars, a eu pour objet d'évaluer la préparation au lancement de tous les éléments de la mission: satellites, charge utile scientifique, secteur sol, système de distribution de données, Centre commun d'opérations scientifiques (JSOC), et interfaces lanceur/satellites. Tous les éléments pris individuellement avaient fait préalablement l'objet d'une revue de recette concluante et la commission chargée de la MFRR a déclaré à l'unanimité leur aptitude au vol.

Le seul point en suspens était celui de savoir si les satellites étaient en mesure de supporter les chocs, plus importants que prévu, occasionnés par la séparation de la coiffe. A la suite de deux programmes d'essais conduits sur le modèle structurel du satellite (modèle équipé de matériel de vol et de charges utiles de rechange au cours du premier essai), les concepteurs d'Ariane-5 ont accepté d'installer des amortisseurs entre chaque empilement de satellites et l'interface avec le lanceur. Les résultats de ces deux essais ont été évalués par un groupe de travail ad hoc réunissant des experts de l'Agence et de l'industrie, qui a autorisé le lancement de Cluster sur une Ariane-5 (V501) équipée d'amortisseurs.

Tous les autres systèmes de soutien sont maintenant prêts pour le lancement, qui doit avoir lieu le 30 mai ou un peu plus tard.

Le lancement sera suivi d'une phase de recette et d'évaluation de trois mois. Les quatre satellites seront ensuite confiés à la communauté scientifique pendant les deux ans que durera la mission.

Huygens

Les décisions prises fin 1995 et début 1996 à la suite des nombreux incidents qui se sont produits ont débouché sur une vision du programme assez différente de celle du dernier bulletin. Les conclusions des études menées sur les effets des chocs pyrotechniques ont réclamé la mise en place d'un test supplémentaire dans la séquence d'essais de recette du modèle de vol de la sonde, tandis que les recherches sur la résistance de l'isolation thermique du module de descente de la sonde montrent qu'il faudra répéter l'essai d'entrée dans l'atmosphère de Titan avec la mousse isolante modifiée.

Pour les expériences du modèle de vol, la situation s'est quelque peu détériorée en raison de nouveaux retards de livraisons et des défaillances qui se sont produites, ce qui nécessitera une nouvelle étude et une nouvelle fabrication. Le programme d'essai du modèle de vol de la sonde se poursuit avec des essais d'éléments des modèles électriques et de qualification et, en cas de besoin, leur échange par des unités de vol programmé à un stade ultérieur. Bien que ce ne soit pas une situation souhaitable, cela ne pose pas techniquement de problème majeur.

SOHO

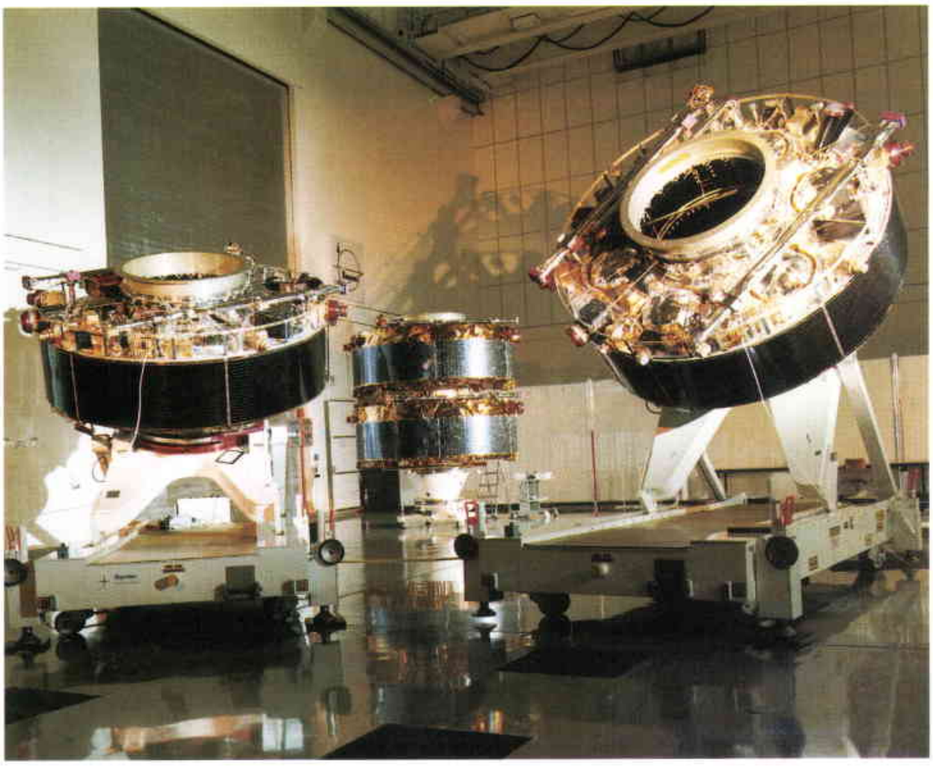
A major milestone was achieved in mid-February when the SOHO spacecraft was successfully injected into its halo orbit. This injection manoeuvre was followed by a series of spacecraft commissioning tests, which have all confirmed the very good performance of the spacecraft.

A first coordinated scientific mini-campaign has already taken place, with simultaneous observations being made by some SOHO instruments together with those of the Japanese solar spacecraft Yohkoh and several ground observatories throughout the world. The specific features of the Sun explored during this campaign were 'polar plumes in the south coronal hole'.

The preparation of two modifications to the on-board software that will enhance the robustness of some system features (particularly attitude and orbit control) was completed in mid-March. Following thorough ground testing with the ESA, NASA and industry simulators, these software patches have been successfully uploaded and tested on the orbiting spacecraft.

La flottille Cluster, composée de quatre satellites, prête au lancement

The four Cluster spacecraft, being readied for launch



ERS-2

The ERS-2 satellite celebrates its first year in orbit on 21 April 1996. The tandem operations with ERS-1 continue to provide unique interferometric images of the Earth based on the Synthetic Aperture Radar (SAR) instrument.

The Commissioning of the ERS-2 Scatterometer is nearing completion and full operational status is expected by mid-May 1996.

Advantage has been taken of the tandem operations to achieve a very precise cross-calibration between the ERS-2 and ERS-1 Radar Altimeters (RAs). Full exploitation of the ERS-1 instrument's twin geodetic phase data has provided a marine geoid with an unprecedented high resolution.

The Global Ozone Monitoring Experiment (GOME) is demonstrating a stable in-orbit performance. The complex ground processing system is still being optimised, the resulting instrument data products being compared with ground-based validation stations. General release of GOME data products is anticipated from April 1996 onwards.

Operation of the Infrared Radiometer (IRR) of the Along-Track Scanning Radiometer (ATSR-2) was interrupted in late 1995 following anomalous behaviour of the radiometer's scanning mechanism. As a result of a series of short in-orbit tests conducted to diagnose the scanning anomalies and to recover the IRR, the performance of the scanning mechanism has improved considerably. IRR operations are therefore expected to resume in April 1996, although close monitoring of in-orbit data and further analysis of the anomaly will continue.

Data from the ERS-2 Precision Range and Range-Rate Equipment (PRARE) is now considered operational, whilst full deployment of the ground stations continues.

The ERS-1 and ERS-2 spacecraft performances remain stable and the next highlight will be the completion of the fifth year of ERS-1 operations on 17 July 1996.

Cluster

The four spacecraft have been fuelled and are undergoing final thermal-hardware integration at the Kourou launch site. Battery conditioning has started and integration and final thermal hardware closeout will commence after Easter. The four spacecraft will be totally readied for a launch on 30 May, as currently foreseen for the first Ariane-5 flight (V501).

The Mission Flight Readiness Review (MFRR) was held at ESTEC at the beginning of March to assess the readiness for launch of all mission elements: spacecraft, scientific payload, ground segment, data dissemination system, Joint Science Operations Centre and launch-vehicle interfaces. All elements had previously successfully undergone individual acceptance reviews and the MFRR Board unanimously agreed the launch-readiness of all elements.

The qualification status of the spacecraft against the greater than expected shock loads coming from fairing separation was the only open point which required further attention. As a result of two test programmes using the spacecraft structural model (equipped during the first test with flight-spare equipment and payload), the Ariane-5 design authority had agreed to install shock attenuators between each spacecraft stack and the launch-vehicle interface. The results of both tests have been evaluated by a Shock

L'ensemble des problèmes évoqués ci-dessus a eu pour résultat un surcroît de travail, l'obligation du travail à deux postes et l'allongement des séquences opératoires, ce qui va augmenter les coûts et reporter de six à huit semaines la recette du modèle de vol. La date de livraison de la sonde sur le site de lancement n'est toutefois pas remise en cause.

Les autres aspects du programme sont satisfaisants. Le modèle d'identification de la sonde, qui est parvenu à un état 'similaire au modèle de vol', sera livré au Jet Propulsion Laboratory (Californie) au mois de mai comme prévu. Les activités du secteur sol suivent leur cours, avec les préparatifs de la revue des installations du secteur sol bien en main.

Les activités de la mission Cassini à la NASA sont en bonne voie, avec la revue critique du lanceur menée à bien en février.

Integral

A la suite de la revue des impératifs système, des mesures spécifiques ont été engagées conjointement avec le maître d'oeuvre, Alenia Spazio (I), pour fixer définitivement les spécifications du système qui régissent la conception du véhicule spatial. Un niveau acceptable de définition ayant été atteint, le processus d'approvisionnement des unités et sous-systèmes a pu commencer. En raison de la communité entre le module de servitude d'Integral et celui du véhicule spatial XXM, ce processus comprend:

- *une revue des offres pour les unités récurrentes réalisées dans le contexte du projet XMM*
- *un nombre limité d'appels d'offres concurrentiels pour les éléments spécifiques d'Integral, en particulier le module de la charge utile.*

L'ISVR, première revue des instruments de la charge utile, est destinée à mieux connaître les instruments et à confirmer les interfaces techniques et de gestion entre le véhicule spatial et la charge utile.

Rosetta

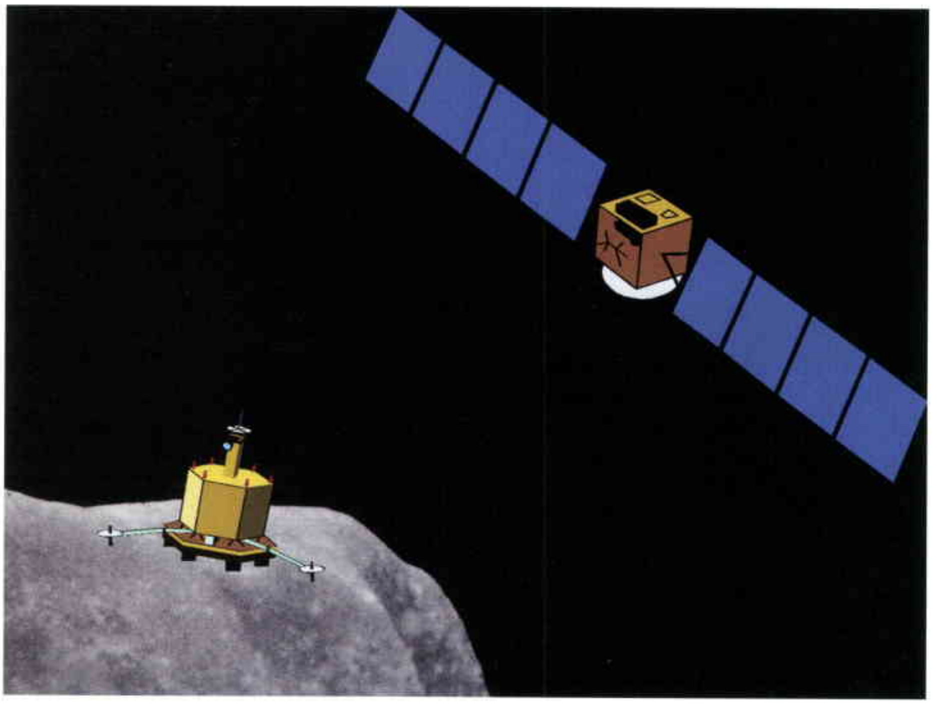
La phase de définition de la mission Rosetta arrive maintenant à son terme. Les études industrielles de soutien au niveau système doivent s'achever à la fin du mois de mars et chaque groupe d'étude présente les résultats de ses travaux lors d'une réunion avec l'industrie européenne le 28 mars. Les documents établis au cours de la phase de soutien ont été mis à la disposition de l'ensemble des groupes industriels.

A sa réunion de février, le Comité du programme scientifique (SPC) de l'ESA a examiné les conséquences sur Rosetta des contraintes budgétaires imposées lors de la session du Conseil au niveau ministériel à Toulouse en octobre dernier. Le SPC a réduit le coût de la mission et exclu du budget affecté au projet la fourniture d'une caméra scientifique ainsi que certains éléments de soutien de la charge utile. La fourniture de ces derniers aurait provoqué un dépassement d'environ 7% du coût à achèvement du projet par rapport à l'objectif fixé. On étudie maintenant la possibilité de disposer d'une caméra scientifique en tant qu'instrument financé par le responsable de recherche, comme il est d'usage.

Toujours à sa réunion de février, le SPC a approuvé le choix de la charge utile scientifique de l'orbiteur Rosetta, qui comprend deux ensembles d'étude scientifique de la surface (SSP) dénommés Champollion et Roland. Parmi les éléments de charge utile proposés, plusieurs sont soit extrêmement complexes, soit de conception très novatrice, de sorte que la définition des interfaces avec le véhicule spatial est encore assez peu précise. Du fait des impératifs liés à la date de lancement, le SPC a accepté que la charge utile proposée soit présélectionnée sous réserve d'une confirmation définitive au bout d'un an. Au cours de la phase de confirmation, chaque instrument devra faire la preuve de sa faisabilité et ses interfaces avec le véhicule spatial devront être arrêtées avant le lancement des activités industrielles de phase B.

L'étape suivante du projet sera l'approvisionnement auprès de l'industrie, qui débutera avec l'envoi de l'appel d'offres en juin 1996. La politique d'approvisionnement suivie pour Rosetta prend en compte les recommandations du SPC visant à réduire les coûts de tous les éléments d'un projet d'au moins 10%. C'est pourquoi une nouvelle politique d'approvisionnement faisant jouer au maximum la concurrence à tous les niveaux a été proposée au Comité de la politique industrielle de l'Agence, qui l'a approuvée à sa réunion de mars.

La phase de définition des autres composants de la mission se poursuit et une commande ferme a été passée à Arianespace pour réserver un lanceur Ariane-5 en janvier 2003. La masse au lancement de Rosetta a été fixée à 2900 kg, y compris la charge utile scientifique, pour laquelle l'hypothèse de référence est de 220 kg.



Artist's impression of the Rosetta mission

Vue conceptuelle de la mission Rosetta

Working Group consisting of Agency and Industry experts, which has now cleared Cluster for flight on V501 using the attenuators.

All other support systems are now in 'readiness-for-flight' configuration in anticipation of a launch on 30 May or shortly thereafter.

Following launch, the four Cluster spacecraft will undergo a three-month commissioning and evaluation phase, before being handed over to the scientific community for their two-year scientific mission.

Huygens

A number of incidents that occurred and decisions that were taken at the end of 1995 and early in 1996 have, together, produced a programme perspective rather different from that last reported in these pages. The conclusions of the studies of the effects of pyrotechnic shocks have resulted in the introduction of a pyrotechnic shock test into the flight-model Probe acceptance testing sequence, while the investigations into the performance of the Probe descent module's foam thermal insulation have determined the need to re-perform the 'Titan entry' test with the modified foam.

The situation with the flight-model experiments has deteriorated somewhat with some deliveries being further delayed and with failures occurring that necessitate some redesign and remanufacture. The flight-model Probe's test programme is being continued with electrical- or qualification-model experiment units where necessary, with the exchanges for full flight units planned at a later stage. Whilst this is not a desirable situation, technically it is not a major problem.

However, the combination of the above elements is resulting in additional work, double shift working and extended timelines, which will increase costs and delay the flight model's acceptance by six to eight weeks. However, the final delivery date to the launch site is not endangered.

Other aspects of the programme are satisfactory. The engineering-model Probe, now in a 'flight-look-alike' condition, will be delivered to the Jet Propulsion Laboratory in California in May as planned.

Ground-segment activities are proceeding normally, with preparations for the Ground Segment Implementation Review well in hand.

The NASA and Cassini mission activities are continuing normally, with a Launch Vehicle Critical Review successfully accomplished in February.

Integral

Following the Systems Requirements Review, special actions were initiated with the Prime Contractor, Alenia Spazio (I), to finalise the system specification which drives the design of the whole spacecraft. An acceptable level of definition having been reached, the procurement process for units and subsystems could be started. Due to the commonality between the Integral Service Module (SVM) and that of the Agency's XMM spacecraft, this process entails:

- a review of the offers for recurring units made in the context of the XMM project
- a limited number of competitive Invitations to Tender for Integral-specific items, mainly for the Payload Module.

The first review of the payload instruments, the Instrument Science Verification Review (ISVR), was commenced with the aim of further assessing the scientific performance of the instruments and confirming the technical and management interfaces between the spacecraft and the payload.

Rosetta

The mission-definition phase for Rosetta is now coming to a close. The industrial system support studies are due to terminate at the end of March and each study group presented the results of their work to a meeting with European Industry on 28 March. The study notes produced during the support phase have been made available to all industrial groups.

At its February meeting, the ESA Science Programme Committee (SPC) debated the effect on Rosetta of the budgetary constraints imposed during last October's Council Meeting at Ministerial Level in Toulouse. The SPC capped the cost of the mission and excluded the provision of a scientific camera and payload-support items from the project budget. Provision of these would have caused the target project cost at completion to be exceeded by some 7%. The scientific camera is now under consideration as a conventional Principal-Investigator-funded instrument.

Also at its February meeting, the SPC endorsed the selection of the Rosetta Orbiter scientific payload, including two Surface Science Packages (SSPs) 'Champollion' and 'Roland'. Several of the proposed payload elements are either extremely complex or highly innovative, and consequently the interface definition with the spacecraft was somewhat vague. Because of the unique launch date, the SPC agreed that the proposed payload be pre-selected and subject to final confirmation after one year. During the confirmation phase, each instrument will have to demonstrate feasibility and its spacecraft interfaces must be firmed up prior to starting the industrial Phase-B.

The next phase of the project is the industrial-procurement phase, which will commence with the issue of the Invitation to Tender in June 1996. The procurement policy to be followed for Rosetta takes into account the recommendations of the SPC to endeavour to reduce all project element costs by at least 10%. Accordingly, a novel procurement policy involving maximum competitiveness at all levels has been proposed, and was agreed by the Agency's Industrial Policy Committee at its March meeting.

The definition phase for other mission constituents is continuing and a firm order has been placed with Arianespace for an Ariane-5 launch vehicle for January 2003. Rosetta's mass at launch has been agreed at 2900 kg, including a basic allocation of 220 kg for the scientific payload.

EOPP

Future programmes

Preparation of the nine reports for assessment for potential Earth Explorer missions has continued throughout the reporting period. Each report has been supported by a mission working group and industrial studies. The reports are to be published in April and will be discussed at a dedicated workshop at the end of May in Granada.

The declaration for the extension of EOPP for the period mid-1996 to 2001 was

EOPP

Programmes futurs

La préparation des rapports d'évaluation de chacune des neuf missions candidates à l'exploration de la Terre s'est poursuivie au cours de la période de référence. Chaque rapport a reçu l'appui des groupes de travail 'mission' et des études industrielles. Les rapports doivent être publiés au mois d'avril; ils seront examinés lors d'un atelier spécialisé fin mai à Grenade.

La déclaration relative à la prolongation de l'EOPP de mi-1996 à 2001 a été approuvée lors du Conseil directeur de février.

Campagnes

Des préparatifs sont en cours pour une nouvelle campagne: INDREX-96 (expérience radar indonésienne). L'ESA est l'un des partenaires du projet associé à cette campagne, qui a pour but la réalisation d'un système de télédétection et de surveillance pour la gestion des forêts et l'utilisation des sols en Indonésie.

The Polar Platform structural model

Modèle structurel de la plate-forme polaire

Envisat-1/Plate-forme polaire

Envisat-1

Le tournant des années 1995 et 1996 a été une période très active pour le programme Envisat. A la demande de certains délégués au Conseil directeur du programme d'observation de la Terre, un certain nombre de revues détaillées a eu lieu sur la situation générale et le coût du programme, pendant que les travaux sur le projet devaient se dérouler comme prévu.

Le point sur le développement des charges utiles et de la plate-forme polaire est l'objet d'une de ces revues (par le DOSTAG), une attention particulière étant portée sur les caractéristiques des instruments, les technologies critiques et le calendrier général du programme. En conclusion, on dispose désormais d'une formule de référence solide pour le programme.

Les objectifs de la mission ont également été réévalués – tant en ce qui concerne l'utilisation scientifique des données que le soutien des applications opérationnelles et commerciales – par un groupe de travail scientifique de haut niveau. Il a été confirmé que la charge utile constitue un ensemble homogène d'instruments, dont aucun ne peut être considéré comme obsolète au vu des récents résultats scientifiques, et que cet ensemble offrira une capacité unique d'observation de la Terre.

Ces revues ont servi à confirmer les objectifs fixés à la mise au point des instruments et qui ont servi de base aux négociations des contrats des 120 sous-systèmes qui ont pris place depuis 18 mois. Toutes les négociations relatives à la réalisation des instruments de la charge utile ont été menées à bon terme début mars. Si la composition de la charge utile a été conservée, toutes les autres possibilités de réduction des coûts continuent d'être recherchées. On a insisté sur la consolidation de la base de référence et sur la rationalisation de tous les travaux de développement et d'essai. Le programme actuel du calendrier, prévoyant un lancement vers mi-1999, est maintenu.

Un contrat forfaitaire pour le SAR de pointe, l'instrument de charge utile Envisat le plus exigeant et le plus délicat, a été conclu avec Matra Marconi Space UK. La signature officielle du contrat de maîtrise d'oeuvre de la mission doit avoir lieu au deuxième trimestre 1996.

Plate-forme polaire

Le programme de modèle de structure a progressé avec l'intégration au niveau plate-forme qui a eu lieu dans les locaux de Matra Marconi Space à Bristol (RU). Les préparatifs sont en cours pour le transport de ce modèle à l'ESTEC, en avril, en vue d'essais mécaniques ultérieurs. Le programme du modèle de structure a été révisé afin d'utiliser HYDRA (la nouvelle table vibrante hydraulique de l'ESTEC) pour l'essai en vibration à venir.

agreed at the February meeting of the Earth Observation Programme Board.

Campaigns

The preparations for a new campaign known as 'INDREX-96' have been in progress. ESA is one of the project partners in this campaign, aimed at the development of a 'Remote Sensing and Monitoring System for Forest Management and Land Cover in Indonesia'.

Envisat-1/Polar Platform

Envisat-1

Late 1995/early 1996 has been a very busy time for the Envisat Programme. At the request of the Earth Observation Programme Board Delegates, a number of detailed reviews addressing the overall status and cost of the programme have taken place, whilst the normal project work had to continue as planned.

The development status of the payload and the Polar Platform has been the subject of one of these reviews (by the DOSTAG), with special attention being paid to instrument performance, critical technologies and overall programme schedule. It was concluded that a 'solid technical baseline exists for the Programme'.

The mission objectives have also been reassessed – both with respect to the scientific use of the data and the support to operational and commercial applications – by a high-level Scientific Task Force. It has confirmed that the payload constitutes a consistent set of instruments, none of which can be considered obsolete in the light of recent scientific results, and that it will indeed provide a unique Earth-observation capability.

The above reviews served to confirm the instrument development objectives baselined for the contract negotiations for the 120 subsystems that have taken place over the last 1.5 years. All negotiations for payload-instrument development were successfully finalised at the beginning of March. Whilst the payload instrument complement has been maintained, all other possibilities for cost savings are being pursued. Attention has focussed on the consolidation of the technical baseline, and the streamlining of all development and test activities. The present programme schedule aiming at a mid-1999 launch is being maintained.

A fixed-price contract for the Advanced Synthetic Aperture Radar (ASAR), one of the Envisat payload's most demanding and critical instruments, has been agreed with Matra Marconi Space UK. Formal signature of the Mission Prime Contract is expected in the second quarter of 1996.

Polar Platform (PPF)

The structural-model programme has progressed with integration at Platform level taking place in the facilities of Matra Marconi Space in Bristol (UK). Preparations are in progress for this model's transport to ESTEC in April for subsequent mechanical testing. The structural-model programme has been revised in order to make use of the HYDRA (the new ESTEC hydraulic shaker test facility) for the forthcoming vibration testing.

The proto-flight Service Module is under final integration at Matra Marconi Space in Toulouse (F). The electrical integration is well-advanced, but some difficulties remain in terms of timely availability of the dual-mode transponder.

Integration of the engineering-model Payload Equipment Bay (PEB) has been completed at Dornier (D) and functional testing and verification are currently in progress.

Several issues related to the interface with, and launch environment of the Ariane-5 vehicle are currently being addressed.

In response to the requests from the Member States participating in the programme to reduce costs still further, the Agency and industry have been making a substantial effort to identify cost reductions and to implement descopings in both hardware and future test activities, which lead, however, to additional development risk. On the basis of the results achieved, a coordinated proposal will be presented to the Earth Observation Programme Board in order to harmonise the present formal programme funding profiles of the Declarations with the actual needs of the programme.

Meteosat

Assembly and integration of the Meteosat Transition Programme (MTP) spacecraft has begun. Its launch is planned for early July 1997 on an Ariane-4 vehicle.

The MTP spacecraft design is the same as that of the Meteosat Operational Programme (MOP) spacecraft, the imaging instrument being a three-channel radiometer. This instrument will allow continuous imaging of the Earth with a resolution at the subsatellite point of 5 km in the infrared (two infrared channels) and 2.5 km in the visible (one visible channel) frequency spectrum.

The spacecraft assembly phase will be completed by the end of August, when the environmental test phase should begin. The final testing of the spacecraft will take place early next year, with the Flight Acceptance Review planned for mid-April 1997. The MTP launch campaign is expected to last two months, through May and June 1997.

Meteosat Second Generation

The main development phase (Phase-C/D) continues to proceed on schedule with a series of Preliminary Design Reviews at subsystem and equipment level, releasing engineering-model manufacture and thermal/mechanical-model manufacture. The final system-level Preliminary Design Review (PDR) is planned for early April 1996.

Negotiations for the three-satellite procurement (MSG-1, 2 and 3) with industry are in process. The recurrent models MSG-2 and MSG-3, to be launched in 2002 and stored in 2003, respectively, are being fully financed by Eumetsat and are being procured on their behalf by ESA.

METOP

During the Preliminary Design Review (PDR) in December 1995/January 1996, a reference configuration, studied during Phase-B1, was evaluated. Evolution of the programmatic baseline during 1995, particularly regarding the payload complement which the Participating States wish to embark on the METOP series, remained incomplete at the time of the

Le prototype de vol du module de servitude est dans sa phase d'intégration finale chez Matra Marconi Space à Toulouse. L'intégration électrique est en très bonne voie; toutefois certains problèmes subsistent quant à la disponibilité du répéteur mode double dans les délais voulus.

L'intégration du modèle d'identification de la case à équipements de la charge utile (PEB) a été terminée chez Dornier (D). Des essais fonctionnels ainsi que des vérifications sont toujours en cours.

Plusieurs questions relatives à l'interface avec le lanceur Ariane-5 font l'objet d'études.

En réponse aux demandes des Etats membres participant au programme au sujet d'une nouvelle réduction des coûts, l'Agence et les industriels ont prodigué leurs efforts pour rechercher des réductions de coût et mettre en oeuvre des allégements de programme tant en ce qui concerne le matériel que les activités d'essai à venir, ce qui n'ira pas sans risques supplémentaires. Sur la base des résultats obtenus, une proposition coordonnée sera présentée au Conseil directeur afin d'harmoniser les profils actuels de financement inscrits dans la Déclaration avec les besoins réels du programme.

Météosat

L'assemblage et l'intégration du satellite du Programme Météosat de transition (MTP) ont commencé. Ce satellite doit être lancé début juillet par un lanceur Ariane-4.

La conception du satellite MTP est la même que celle du satellite du Programme Météosat opérationnel puisque l'instrument imageur est un radiomètre à trois canaux. Cet instrument prend en continu l'image de la Terre avec une résolution au point subsatellite de 5 km dans l'infrarouge et de 2,5 km dans le visible.

La phase d'assemblage du satellite sera terminée fin août, date à la laquelle la phase d'essais d'ambiance devrait débuter. L'essai final du satellite aura lieu début 1997 et la revue de recette pour le vol est prévue pour mi-avril 1997. La campagne de lancement du MTP devrait durer deux mois (mai-juin 1997).

Météosat de deuxième génération

La phase principale de réalisation (phase C/D) se poursuit selon le calendrier prévu par une série de revues préliminaires de conception (PDR) au niveau des sous-systèmes et des équipements, avec pour objectif de lancer la fabrication du modèle d'identification et du modèle thermique/mécanique. La PDR finale au niveau système est fixée à début avril 1996.

Les négociations avec l'industrie relatives à l'approvisionnement de trois satellites (MSG-1, 2 et 3) suivent leur cours. Les modèles récurrents MSG-2 et MSG-3, le premier devant être lancé en 2002 et le deuxième entreposé à partir de 2003, sont entièrement financés par Eumetsat et approvisionnés par l'Agence pour le compte d'Eumetsat.

METOP

La revue préliminaire de conception (PDR) de décembre 1995/janvier 1996 a donné lieu à l'évaluation d'une configuration de référence étudiée au cours de la phase B1. En 1995, la mise au point de la base de référence programmatique, notamment en ce qui concerne les charges utiles que les Etats participants souhaitent embarquer à bord des satellites METOP, n'était toujours pas achevée au moment de la PDR. La revue a donc été suivie d'une 'phase d'attente' pendant laquelle les activités industrielles ont été réduites à un strict minimum et axées sur les éléments de la conception qui ne dépendent pas de la composition de la charge utile.

Les Etats participant aux programmes METOP de l'ESA et d'Eumetsat semblent parvenir aujourd'hui à une convergence de vues sur la définition de la charge utile. Il s'agirait de retenir l'ASCAT et les autres éléments, à l'exception du ScaRaB (supprimé), de l'OMI (dérivé du GOME d'ERS-2) et du MIMR (qui pourrait toutefois être réembarqué s'il était proposé en tant qu'instrument AO). Un système GPS de précision adapté à l'utilisation des signaux GPS pour le sondage de l'atmosphère est également prévu. Si ces éléments devaient constituer la charge utile de référence, la phase B2 redémarrerait début avril 1996.

Programmes spatiaux habités

Programme de Station spatiale internationale (ISS)

Afin de respecter les plafonds financiers du programme ISS approuvé, un ajustement de la répartition des tâches industrielles a été étudié dans le cadre d'une évaluation conduite à l'échelle du programme, portant sur les mesures à prendre pour aboutir à des réductions de coût équivalant aux montants bloqués, fixés à 2,03% dans la Déclaration de programme, et pour atteindre les objectifs globaux de retour géographique. Dans cette perspective, des réunions ont été organisées avec les délégations des principaux contributeurs au programme ISS afin d'examiner le rôle de leurs industriels et leurs souhaits quant à l'utilisation des installations nationales nécessaires au soutien de la phase opérationnelle. Une attention particulière a été accordée aux mesures spéciales en faveur de l'Italie décidées à la session du Conseil au niveau ministériel à Toulouse en octobre dernier.

COF

Tous les points de non-conformité technique par rapport aux impératifs de la base de référence commune ESA/NASA ont été résolus et le contenu et le prix de l'ensemble des travaux au titre du contrat de développement du secteur spatial ont été approuvés. Des activités industrielles sont en cours en ce qui concerne la mise au point finale des spécifications et des plans, la consolidation de la configuration générale, la réalisation de systèmes avioniques pour le logiciel au sol et d'équipements électriques de soutien sol. En outre, les modèles de développement de certains des systèmes de contrôle d'ambiance et de soutien vie sont en cours d'essai dans le cadre des activités d'approvisionnement communes au COF et au MPLM. La fabrication de l'unité d'essais de structure du MPLM (sur laquelle est basée la structure du COF) a été menée à bien et des préparatifs sont en cours pour conduire les essais de qualification.

Sur le plan programmatique, le calendrier a été adapté en vue d'un lancement en novembre 2002 et les derniers détails de la répartition des tâches industrielles sont en cours de règlement, l'objectif étant d'accroître au maximum le contenu européen chaque fois que les prix proposés l'autorisent.

PDR. Consequently, the Review was followed by a holding phase during which industrial effort was kept to a minimum, focussing on those design elements that are independent of the payload complement.

The Participating States to both the ESA and Eumetsat programmes now appear to be converging on a payload definition. This retains the ASCAT and the other payload elements except ScaRaB which is removed, OMI which is realised as GOME, as flown on ERS-2, and MIMR, where provision is made for its possible re-embarkation if it should be offered as an Announcement of Opportunity instrument. In addition, a precision GPS system adapted to use the GPS signals for atmospheric sounding will be included. Assuming this becomes the baseline payload, Phase-B2 will be restarted in early April 1996.

Manned Space Programme

International Space Station Programme (ISS)

In order to respect the financial ceilings of the approved ISS Programme, adjustment of the distribution of industrial tasks was investigated as part of a programme-wide assessment of the measures to be undertaken to achieve cost reductions equivalent to the 2.03% blocked amount in the Programme Declaration, and to meet the overall geographical-return targets. To this end, meetings have taken place with the Delegations of the main ISS Programme contributors to discuss the role of their Industry, and their aspirations with respect to the use of national facilities needed to support the operational phase. Particular attention has been paid to the special measures for Italy agreed at the Council Meeting at Ministerial Level in Toulouse last October.

COF

All technical non-compliances against the ESA/NASA joint requirements baseline have been resolved and the total work content/price of the space-segment development contract has been agreed. Industrial work in the domains of specifications/plans finalisation, overall configuration design consolidation, ground software avionics facility development and electrical ground-support equipment development is underway. Furthermore, the development models of some of the environmental-control and life-support systems are being tested as part of the common COF/MPLM procurement activity. Manufacture of the structural test unit of the MPLM (on which the COF structure is based) has been completed and it is being prepared for qualification testing.

Programmatically, the adjustment of the schedule to a launch date of November 2002 has been made, and fine tuning of the industrial worksharing is being finalised, with the goal of maximising European content wherever this is compatible with the price.

CRV/CTV

The parallel CRV/CTV Phase-A studies were completed as planned by the end of 1995. A bridging phase from January to mid-April 1996 will provide additional technical data in support of open concept choices, such as the landing system. The Request for Quotation for Phase-B, which is planned to start in September 1996, is in preparation and will consider the use of a single contractor.

ATV

The system requirements and the system design as frozen at the System Requirements Review (SRR1) in December 1995 remain valid and will be finalised in May after completion of the Phase-B Extension. A change of prime contractor after Phase-B is envisaged and will be taken into account in the preparation of Phase-C/D. The new prime contractor will be made familiar with the overall programme, and in particular the ATV Rendezvous Pre-development Programme, to the extent necessary to ensure that the results are fully beneficial for the ATV Programme.

Discussions and studies with the Russian Space Agency (RKA) and the Russian contractors concerning the interfacing of the ATV with the Russian part of the Space Station for reboost have progressed well and all inherent technical aspects seem to have been addressed satisfactorily.

The Russian equipment that could be used on ATV has been defined and the profile of the first ATV demonstration flight has been worked out with the Russian contractor.

Technology and ARD

With few exceptions as far as ongoing ARD work is concerned, all technology contracts have been committed and are proceeding as planned.

Good progress has been made with the assembly and testing of the Atmospheric Reentry Demonstrator (ARD) in industry. The delay in the delivery of the ARD propulsion system was overcome by adapting the planning of the integration and test accordingly. Preparations are being made to repeat the failed balloon drop test, the necessary additional funds having been made available within the scope of the MSTP budget.

Preparations for the launch of the ARD in September 1996 on the Ariane-5 second demonstration flight have continued on schedule.

Early deliveries

Columbus Mission Data Base (MDB)

The formal delivery and installation of the Columbus Mission Data Base into the NASA Mission Build Facility in Houston took place in December, thus concluding this phase of the activity in line with the schedule agreed with NASA in early 1994. Prototyping activities for further possible deliveries to NASA under a separate contract have been initiated.

Core Data Management System for the Service Module (DMS-R)

The ongoing development work in industry was complemented by a series of technical meetings in Russia with the participation of the Russian Space Agency, and the European and Russian industrial partners, to negotiate open technical changes and revised delivery dates, as agreed with NASA. Agreement was reached on all points.

European Robotic Arm (ERA)

Negotiations with the ERA Prime Contractor culminated in the signing of the contract for the ERA Development Part 2. The final details of the subcontractor arrangements remain to be settled. A competitive tender was issued for provision of the ERA Mission Preparation and Training Equipment.

Consideration is being given by NASA and RKA to a change in the International Space Station launch sequence whereby the Russian Scientific and Power Platform, on which the ERA is operated, would be

CRV/CTV

Les études parallèles de phase A du CRV et du CTV ont été achevées comme prévu fin 1995. Une phase de transition allant de janvier à la mi-avril 1996 fournira des données techniques complémentaires, qui permettront d'arrêter les concepts non encore fixés, comme le système d'atterrissage. La demande de prix relative à la phase B, qui doit être lancée en septembre 1996, est en cours de préparation et il est prévu de faire appel à un contractant unique.

ATV

Les impératifs et le concept au niveau système qui avaient été arrêtés lors de la revue des impératifs système (SRR1) en décembre 1995 restent valables et feront l'objet d'une mise au point définitive en mai, à l'issue de la prolongation de la phase B. Un changement de maître d'oeuvre est envisagé après la phase B et la préparation de la phase C/D sera conduite dans cette perspective. Le nouveau maître d'oeuvre sera familiarisé avec l'ensemble du programme, notamment le programme de prédéveloppement du système de rendez-vous de l'ATV, jusqu'à ce que les résultats obtenus bénéficient intégralement au programme ATV.

Les discussions et études conduites avec l'Agence spatiale russe et les contractants russes au sujet des interfaces entre l'ATV et la composante russe de la Station spatiale ont bien avancé et tous les aspects techniques du problème du rehaussement d'orbite semblent avoir été résolus de manière satisfaisante.

L'équipement russe susceptible d'être utilisé sur l'ATV a été défini et le profil du premier vol de démonstration de l'ATV a été établi avec le contractant russe.

Technologie et ARD

En ce qui concerne les travaux en cours sur l'ARD, tous les contrats technologiques ont été engagés à quelques exceptions près et leur exécution se déroule normalement.

D'importants progrès ont été réalisés dans l'assemblage et l'essai du démonstrateur de rentrée atmosphérique (ARD) par l'industrie. Le retard survenu dans la fourniture du système de propulsion de l'ARD a été compensé par un remaniement en conséquence du calendrier d'intégration et d'essai. Des préparatifs sont en cours pour reprendre l'essai de largage par ballon qui avait échoué, les crédits supplémentaires nécessaires ayant été dégagés au titre du budget MSTP.

Les préparatifs en vue du lancement de l'ARD en septembre 1996 lors du deuxième vol de démonstration d'Ariane 5 se sont poursuivis conformément au calendrier.

Livraisons à court terme

Base de données mission Columbus (MDB)

Le transfert officiel et l'installation de la MDB dans les Moyens de préparation de mission à Houston ont eu lieu en décembre, mettant ainsi un point final à cette phase d'activités, conformément au calendrier fixé avec la NASA début 1994. Des travaux de réalisation de prototypes ont été lancés en vue d'éventuelles fournitures ultérieures à la NASA au titre d'un contrat distinct.

Système principal de gestion des données pour le module de servitude (DMS-R)

Les travaux de développement en cours au sein de l'industrie ont été complétés par la tenue, en Russie, d'une série de réunions techniques, auxquelles ont participé l'Agence spatiale russe et les partenaires industriels européens et russes afin de négocier certains points en suspens portant sur des modifications techniques et sur les dates de livraison conformément aux accords conclus avec la NASA. Un accord a été obtenu sur tous les points.

Bras télémanipulateur européen (ERA)

Le fait marquant des négociations avec le maître d'oeuvre de l'ERA a été la signature du contrat relatif à la 2ème partie de ses travaux de développement. Il reste à régler les derniers détails des arrangements avec les sous-traitants. Un appel d'offres concurrentiel a été envoyé pour la fourniture des moyens de formation et de préparation de mission ERA.

La NASA et la RKA examinent actuellement une modification de la séquence de lancement de la Station spatiale internationale consistant à faire exécuter par la Navette américaine le lancement de la plate-forme Science et énergie, qui doit être fournie par la Russie et sur laquelle l'ERA doit être utilisé. Les tâches de l'ERA resteraient pour l'essentiel inchangées, mais les conséquences de ce nouveau scénario de lancement sont en cours d'évaluation.

Equipements de soutien de laboratoire

Congélateur – 80°

La phase B s'est poursuivie selon le calendrier prévu, bien que la technologie de pointe utilisée ait entraîné des difficultés, qui risquent de se traduire par quelques hausses de coût lors de la phase C/D. La revue programmatique a eu lieu en décembre et l'essai du modèle de développement a débuté.

Boîte à gants pour la recherche en microgravité

La fabrication du modèle de développement a commencé; l'intégration et l'essai sont prévus pour la fin de premier trimestre 1996. La revue préliminaire de conception, programmée en décembre 1995, a été reportée à mars 1996.

Hexapod

La première grande revue de la phase B, qui consistait à examiner les impératifs système et la configuration préliminaire, a eu lieu en décembre comme prévu. L'ensemble de la phase B reste conforme au calendrier.

Recherche en microgravité

La mission EuroMir 95 s'est achevée le 29 février 1996. Les dix-huit expériences en sciences de la vie et huit expériences en sciences des matériaux du programme de recherche en microgravité ont été conduites soit en mode autonome, soit dans les trois installations nouvelles à utilisateurs multiples. La masse totale de la charge utile fournie par le programme en question avoisinait les 350 kg.

Le 2 mars 1996, un instrument de physique des fluides conçu pour étudier les déplacements des bulles de gaz dans un champ à gradient thermique bien défini en milieu liquide a été embarqué à bord d'une fusée-sonde Texus 34, lancée de Kiruna (S). Le chercheur responsable de cette expérience l'a réalisée en temps réel depuis son laboratoire de Naples (I), en mode interactif.

En 1996, qui sera une année de travail intense, le programme de recherche en microgravité prévoit les lancements suivants:

launched on the Shuttle. The tasks of the ERA would remain substantially the same, but the implications of the new launch scenario are being assessed.

Laboratory Support Equipment

80° Freezer

The Phase-B has continued on schedule, although difficulties with the advanced technology employed have given rise to some potential cost increases for Phase-C/D. The programmatic review took place in December and the development model test was initiated.

Microgravity Science Glovebox

Manufacture of the development model has been initiated; integration and testing is planned for the end of the first quarter of 1996. The Preliminary Design Review foreseen for December 1995 was rescheduled for March 1996.

Hexapod

The first major review of the Phase-B, the system requirements and design configuration review, took place in December as planned. Overall, the Phase-B remains on schedule.

Microgravity

The EuroMir 95 mission was concluded on 29 February 1996, with the Microgravity Programme having contributed 18 life-science and 8 materials-science experiments, which were performed either as self-standing experiments or in three newly developed multi-user facilities. The total mass of the payload provided by the Microgravity Programme was approximately 350 kg.

On 2 March 1996, a fluid-physics payload designed to investigate the motion of gas bubbles in a well-defined thermal-gradient field in a fluid was successfully flown on the sounding rocket Texus 34, launched from Kiruna (S). This experiment was performed interactively in real time by the researcher located at his home institute in Naples (I).

1996 is a year of high activity for the Microgravity Programme, with the following launches:

- 21 March 1996: Flight of Biorack in Spacehab on Shuttle mission SMM-03.
- 23 April 1996: Launch of the sounding rocket Maser 7.
- 16 May 1996: Flight of the Diffusion Coefficient Measurement Facility on Shuttle mission STS-77.
- 27 June 1996: Flight of four multi-user facilities – the Advanced Gradient Heating Facility, the Advanced Protein Crystallisation Facility, the Bubble, Drop and Particle Unit, and the Torque Velocity Dynamometer – on the LMS Spacelab mission.
- September/October 1996: the Foton-11 mission carrying the Biobox and the Biopan and three autonomous experiments.
- December 1996: A further reflight of Biorack on Shuttle mission SMM-05.

In preparation for Space Station Utilisation, definition studies are being initiated for three major multi-user facilities: the Materials Science Laboratory (MSL), the Fluid Science Laboratory (FSL) and the Biolab (BL).

EuroMir 95

The EuroMir 95 mission came to a successful close at 11.42 h CET on 29 February 1996 with the safe landing of the Soyuz TM-22 spacecraft in the steppes of Kazakhstan. At the landing site, about 107 km northeast of the town of Arkalyk, ESA astronaut Thomas Reiter was welcomed back to Earth by backup astronaut Christer Fuglesang, his prime contact person at the Control Centre during the mission.

Less than seven hours later, Thomas Reiter and his Russian crewmates Yuri Gidzenko and Sergei Avdeev arrived at Star City's airport near Moscow, where they were greeted by Russian space authorities, top ESA officials, and numerous members of the EuroMir ground operations and management teams. First medical examinations confirmed the crew's excellent health after their 180 days in orbit aboard the Russian space station Mir.

After just one day of recovery, the crew were ready to give their first international press conference at Star City after their return. According to Thomas Reiter, the absolute highlights of mission for him were the two spacewalks that he made on 20 October 1995 and on 8 February 1996, the first ever undertaken by an ESA astronaut.

The accumulated data from the 41 experiments carried out onboard Mir is now in the hands of the scientists on the ground, who are analysing it together with the material returned and who will soon have their first briefings with the astronauts. The experiment programme spans the fields of life science, astrophysics, material science and technology. Thanks to the 45-day extension of the flight, all of the scientific experiments that had been scheduled could be conducted at least the requisite number of times, and sometimes more.

Thomas Reiter's post-flight programme, consisting of rehabilitation periods, medical examinations, debriefings and public appearances, etc. will continue until the end of June.

- 21 mars: emport du Biorack à bord du Spacehab dans le cadre de la mission SMM-03 de la Navette
- 23 avril: lancement de la fusée-sonde Maser 7
- 16 mai: emport de l'instrument de mesure du coefficient de diffusion dans le cadre de la mission STS-77 de la Navette
- 27 juin: emport de quatre installations à utilisateurs multiples (four à gradient de haute technologie; installation de cristallisation des protéines de pointe; dispositif bulles, gouttes et particules; dynamomètre force-vitesse) dans le cadre de la mission LMS du Spacelab
- septembre/octobre: mission Photon-11 emportant le Biobox, le Biopan et trois expériences autonomes
- décembre: nouvel emport du Biorack dans le cadre de la mission SMM-05 de la Navette.

En préparation de l'utilisation de la Station spatiale, des études ont été mises en route pour définir trois installations importantes à utilisateurs multiples: le laboratoire de sciences des matériaux (MSL), le laboratoire de sciences des fluides (FSL) et le Biolab (BL).

EuroMir 95

La mission EuroMir 95 s'est terminée avec succès le 29 février 1996 avec l'atterrissage à 11h42 (heure de Paris) de la capsule Soyouz TM-22 dans les steppes du Kazakhstan. Sur les lieux de l'atterrissage à environ 107 km au nord-est d'Arkalyk, l'astronaute de l'ESA Thomas Reiter a été accueilli par sa doublure, Christer Fuglesang, qui avait été son principal interlocuteur au Centre de contrôle pendant toute la durée de la mission.

Sept heures plus tard, Thomas Reiter et ses co-équipiers russes, Iouri Guidzenko et Sergueï Avdeïev, sont arrivés à l'aéroport de la Cité des Etoiles près de Moscou, où ils ont été félicités par les autorités spatiales russes, les hauts dirigeants de l'ESA et de nombreux représentants des équipes qui avaient assuré les opérations au sol et la gestion de la mission. Les premiers examens médicaux ont confirmé l'excellent état de santé de l'équipage après cette mission de 180 jours en orbite à bord de la station russe Mir.

Après 24 heures de repos, l'équipage était prêt à donner sa première conférence de presse internationale à la Cité des Etoiles. Pour Thomas Reiter, les étapes les plus marquantes de la mission furent les deux sorties extra-véhiculaires du 20 octobre 1995 et du 8 février 1996, les premières jamais entreprises par un astronaute de l'ESA.

Les données des 41 expériences menées à bord ainsi que le matériel récupéré se trouvent désormais entre les mains des chercheurs, qui procèdent à leur analyse. Chercheurs et astronautes se réuniront bientôt pour faire le bilan de ces expériences, qui portaient sur les disciplines suivantes: sciences de la vie, astrophysique, sciences des matériaux et technologie. Grâce à la prolongation de 45 jours du vol, toutes les expériences scientifiques ont pu être conduites autant de fois qu'il était prévu, voire plus.

Le programme de Thomas Reiter après son séjour en orbite (réadaptation, examens médicaux, comptes rendus de mission, relations publiques, etc.) se poursuivra jusqu'à fin juin.

The EuroMir 95 crew in orbit: from left to right, cosmonauts Sergei Avdeev and Yuri Gidzenko, with ESA astronaut Thomas Reiter

L'équipage l'EuroMir 95 en orbite: à gauche, les cosmonautes Sergei Avdeev et Yuri Gidzenko, á droite l'astronaute de l'ESA Thomas Reiter

In Brief

First Ariane-5 Test Flight Fails

The first test flight of the new Ariane-5 launcher ended in failure in Kourou, French Guiana, on 4 June, with the explosion of the vehicle shortly after lift-off. The four Cluster scientific spacecraft that made up the payload were lost in the explosion.

This was the first proving flight of an entirely new vehicle with engines ten times more powerful than those of the current Ariane-4 series. The many qualification reviews and ground tests conducted throughout the ten-year development programme have involved extremely rigorous checks on the correctness of all the engineering choices made. Unfortunately, however, there is no absolute guarantee of success at the first attempt with such a complex system.

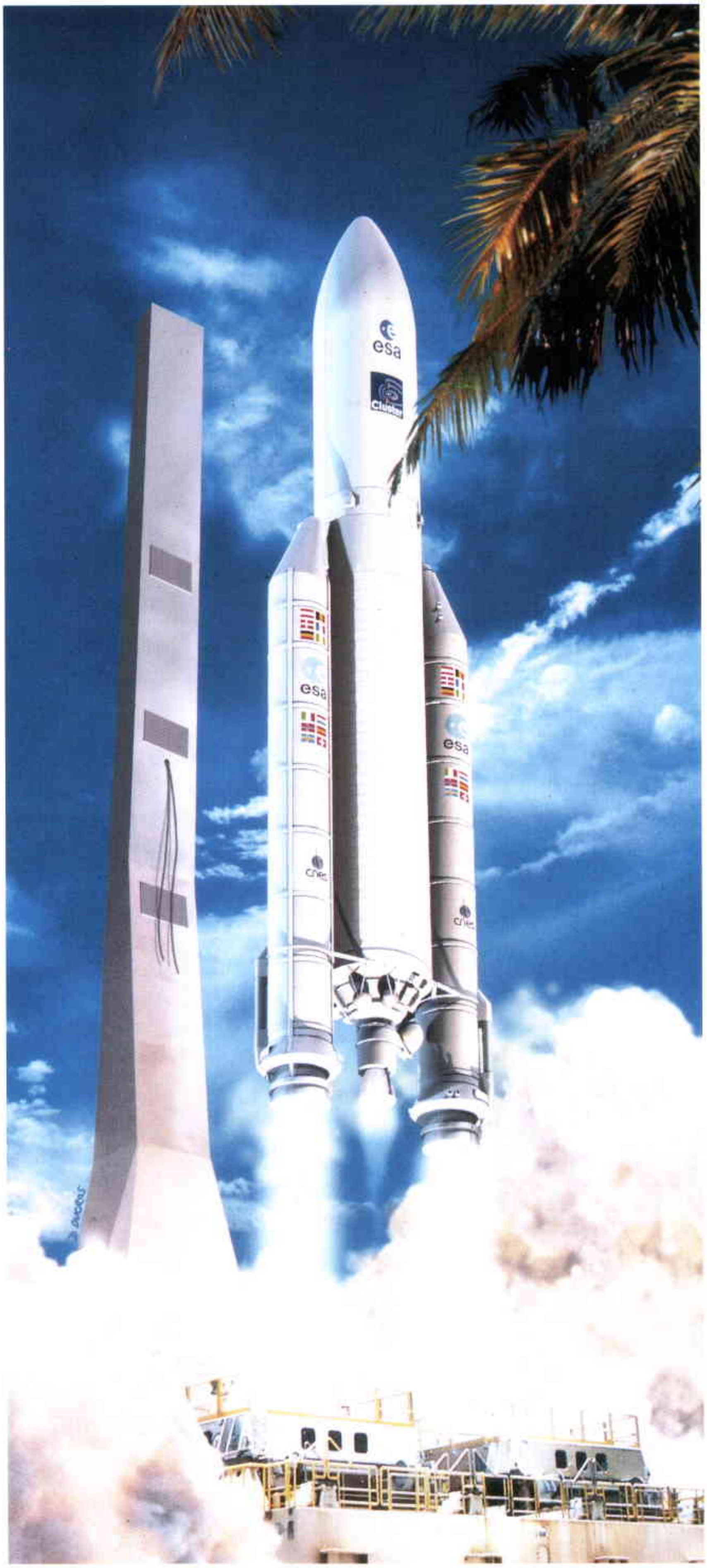
Nominal ignition of Ariane-5's Vulcain engine at 09.33.59 hrs Kourou time was followed by correct ignition of the solid-booster stages and lift-off 7.5 s later. For the next 30 s of the flight, guidance and trajectory were normal, with the launcher reaching Mach 0.7 (857 km/h) and an altitude of 3500 m. Telemetry data show that immediately thereafter, the nozzles of both of the solid boosters suddenly swivelled to their limit, causing the vehicle to tilt sharply and thereby giving rise to excessive aerodynamic loading and breakage of its structure. This loss of launcher integrity was followed by the destruction of all launcher elements by the onboard safety system.

Preliminary analysis of the telemetry data confirms that Ariane-5's solid boosters and cryogenic main stage functioned correctly during the flight, and the launcher's 'electrical and software system' is presently under scrutiny.

An independent Inquiry Board is being set up by ESA and CNES which will report its findings by mid-July and propose corrective measures to prevent any repetition of this extremely unfortunate accident.

The fact that the launcher's performance was completely nominal during the critical first half minute of flight, and the skills and determination to succeed on the part of all those involved – at CNES, at ESA and in European Industry – provide every confidence that the second proving flight, scheduled to take place later this year, will be a complete success.

The Inquiry Board's findings and the latest programme status will be reported in the next issue of the ESA Bulletin (No. 87) in August.



ESA Astronaut Ends Longest Mission by a Non-Russian

ESA Astronaut Thomas Reiter (bottom left) with his Russian crewmates

ESA astronaut Thomas Reiter recently returned from his record-breaking mission aboard the Russian space station Mir. At 180 days, he has become the non-Russian astronaut to have spent the longest time in orbit.

EuroMir 95, a joint ESA – Russian Space Agency mission, ended on 29 February when the Soyuz TM-22 capsule carrying Reiter and his two Russian colleagues landed in the steppes of Kazakhstan. They had been orbiting the Earth aboard Mir since early September 1995. They left behind their two-man, Russian relief crew. The NASA astronaut Shannon Lucid has since joined that crew, remaining aboard Mir after a Space Shuttle docking in March.

During his stay, Reiter performed two 'space walks'. On the first of these, he attached a European experiment to the exterior of the Spektr module. It exposed materials to space and collected space debris and cosmic dust. On the second walk, he retrieved two of the experiment's cassettes, which are currently being analysed back on Earth.

In April, Thomas Reiter was awarded the 'Order of Friendship Medal' by Russian President Boris Yeltsin, in recognition of his 180-day flight. His two crewmates on the EuroMir 95 flight, Commander Yuri Gidzenko and First Engineer Sergei Avdeev, and about 30 other eminent persons from the space community, received similar decorations in a ceremony at the Kremlin in Moscow on 12 April 1996. This day is celebrated as 'Cosmonaut's Day' in Russia, marking the anniversary of the first manned space flight by Yuri Gagarin. The same award had been presented previously to ESA's EuroMir 94 Astronauts Ulf Merbold and Pedro Duque.

Thomas Reiter was accompanied at the ceremony by ESA's Director of Manned Spaceflight and Microgravity, Mr Jeorg Feustel-Büechl, by the Euromir Programme Manager, Dr. Dieter Andresen, and by the Head of the ESA Permanent Mission in Russia, Mr Alain Fournier-Sicre.

During the ceremony, Mr Reiter delivered a well-received message of thanks in Russian to the assembled gathering. Later, Mr Feustel-Büechl was given the opportunity to address President Yeltsin directly on behalf of ESA. After thanking Mr Yeltsin for the honour bestowed on the ESA Astronaut, Mr Feustel-Büechl referred to the joint ESA – Russian mission which had just come to an end: *'We are very proud of this great success, which was the longest mission an ESA astronaut has ever undertaken, and we have particularly appreciated the friendly and cooperative atmosphere in which this enterprise has been performed at all levels. This peaceful cooperation with Russia as a great space nation was a splendid and exciting experience for us, and I am sure that we will have many more opportunities to develop our future cooperation in space'*, he said.

Russian President Boris Yeltsin, in discussion with Mr Feustel-Büechl (right) and Dr Andresen

SOHO Unmasks the Sun

After less than one month of full operation, and five months since its launch on 2 December 1995, ESA's Solar and Heliospheric Observatory, SOHO, has begun to provide remarkable data that could finally lead to the unravelling of the Sun's mysteries. The first results are all the more impressive because SOHO arrived at its vantage point 1 500 000 km out in space only in February, and commissioning was formally completed as recently as 16 April.

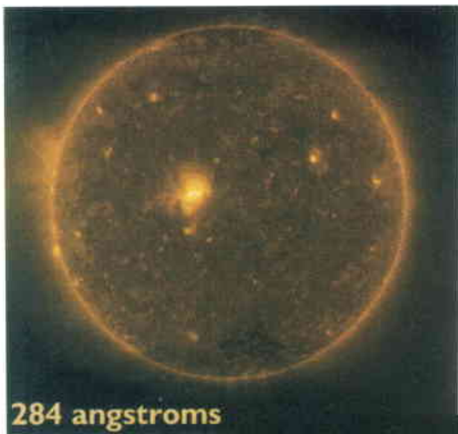
SOHO's payload of twelve scientific instruments includes an extreme ultraviolet imaging telescope, two ultraviolet spectrometers and an ultraviolet coronagraph (an imager for the outer atmosphere) which are being used to study the Sun layer by layer, from its deep interior to the far reaches of the solar wind, over a wide range of wavelengths.

The Sun is currently in the very quietest phase of its eleven-year cycle of activity and appears very calm to those studying it from ground-based observatories. Unencumbered by the masking effects of the Earth's atmosphere, SOHO's instruments show that this supposedly quiet Sun is in fact belching out huge volumes of gas into space. They have also detected currents of gas flowing just beneath the Sun's visible surface, and mapped a hole burnt by the solar wind in a stream of gas coming from the stars.

The observations being made in this 'quiet' phase of the solar cycle, when sunspots are scarce, will provide an excellent baseline for SOHO's later investigations during stormier and more confused periods of solar activity. These will occur around the year 2000, as the Sun enters its phase of maximum activity, with a dramatic increase in the number of sunspots and huge explosions becoming commonplace.

'Everyone is impressed by SOHO's performance', confirms Dr Roger Bonnet, Director of ESA's Scientific Programme; *'By the end of this mission, we will know the Sun far better than we do now. Then we will understand the stars better too, because the Sun is the star we see with greatest clarity. Also, we will be able to comment with much more confidence on those important but puzzling aspects of solar behaviour that affect our lives on Earth, whether in terms of short-lived magnetic storms or long-lasting changes of climate'.*

The next issue of ESA Bulletin (No. 87, August 1996) will contain a special article devoted to the early scientific results from SOHO, written by the ESA SOHO Project Scientist Dr Vicente Domingo and his colleagues.



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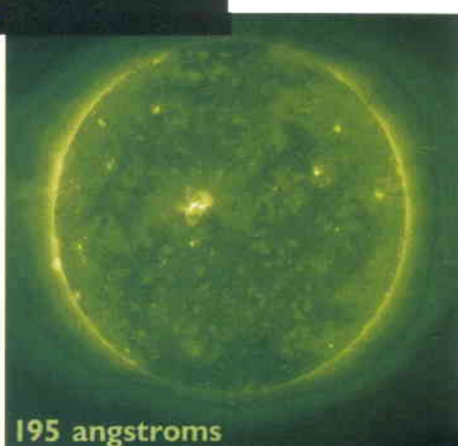

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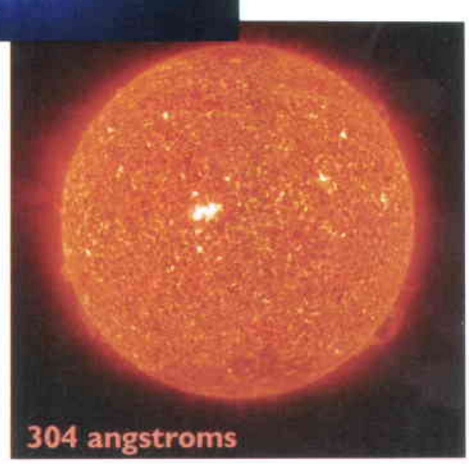

80,000 DEG. C

Figure 1. Temperature levels in the Sun's atmosphere, recorded with SOHO's Extreme Ultraviolet Imager (EIT) instrument

High-Performance Communications Payload Ready for Launch

ESA's European Land Mobile Services (EMS) payload, which will provide a variety of L-band satellite services principally to mobile users throughout Europe and northern Africa, will now be launched on the Italsat-F2 satellite developed by the Italian Space Agency (ASI).

After its launch and commissioning, EMS's capacity will be leased by ESA to Nuova Telespazio, which will serve both as a wholesaler of that capacity to third-party service providers and as a service provider in its own right.

This high-performance communications payload, developed under ESA contract by Alenia Spazio, will allow users with small portable terminals or vehicle-mounted terminals to have access to communications at very reasonable costs. It will be the beginning of a service that will carry on well into the next century. Follow-on payloads, for which ESA is now developing the technology, will be used to provide that continuity of service.

The EMS payload will be orbited as a passenger on Italsat-F2, which is scheduled for launch by Ariane this summer. After the launch and commissioning of the payload, Nuova Telespazio will assume responsibility. It will market services including voice, data and facsimile communications to and from mobile terminals mounted on cars and trucks. The Italsat satellite will complement the services available from terrestrial cellular systems and provide a number of additional types of service. The coverage area will be Greater Europe, extending to North Africa and the Middle East.

Andrea Pucci (left), Chief Executive Officer of Nuova Telespazio, and René Collette, Director of ESA's Telecommunications Programme, signing the contract providing for the lease of EMS capacity to Nuova Telespazio

Royal Visitors to ESTEC

Prince Willem Alexander of The Netherlands and Prince Phillip of Belgium visited the world-class spacecraft testing facilities at ESA's Space Research and Technology Centre, ESTEC, in The Netherlands, in February.

From left to right: Marius Lèfevre, Director of ESTEC, Prince Willem Alexander, Prince Philip and Peter Brinkmann, Head of ESTEC's Testing Division

ESA Astronauts Complete International Mission

ESA astronauts Claude Nicollier and Maurizio Cheli returned weary but satisfied on 9 March from their almost 16-day-long mission aboard the Space Shuttle 'Columbia' (STS-75). It had proven to be an eventful one, with the main payload malfunctioning and the mission being extended by two days.

During the first part of the mission, a satellite was deployed on the end of a 20.7 km-long conductive tether, just 2.54 mm thick. This tether, which generates high voltages, was successfully unreeled to a length of 19.7 km over a period of nearly five hours, but then suddenly broke. The satellite was flung into a higher orbit, dragging the broken tether – which was more than 19 km long – below it. After much evaluation, it was decided not to try to retrieve the satellite. The reason for the break is still under investigation.

Despite the brevity of the experiment, more data than had been expected was collected. The experiment was able to prove that tethers could be used to generate electricity and to place satellites into a higher orbit. Electricity flowed between the satellite and the Shuttle as the conductive tether passed through the Earth's magnetic field lines. Shortly before the break, scientists reported that the tether was generating a voltage of 3500 V and a current of 480 mA.

Mission management was also able to set up ground stations to communicate with the satellite, within hours, thereby creating a new mission. Three-days' worth of data was collected from the experiments onboard the satellite before its battery ran out (unlike larger satellites, it did not have solar panels).

Maurizio Cheli

There are currently no further missions planned for tethered satellites, although their potential for the International Space Station is being considered.

ESA mission specialists Nicollier and Cheli played important roles during the deployment. Nicollier served as the satellite 'navigator', keeping a close watch on its position and movements. Cheli, meanwhile, operated a laser range-finder to accurately gauge the distance of the satellite from the Shuttle.

The mission marked the first time that two ESA astronauts had flown together. A third European, Umberto Guidoni of the Italian Space Agency, was also part of the seven-member crew.

Claude Nicollier

ESA Continues to Address Space-Debris Issue

The number of nations and organisations that make use of space continues to grow and the space debris issue is becoming increasingly urgent. Space debris, however, is a global problem and thus global cooperation in addressing the issue is essential.

ESA is a founding member of one organisation that is addressing the problem, the Inter-Agency Space Debris Coordination Committee (IADC). The group's main purpose is to exchange information on space-debris research between member space agencies and to identify debris mitigation options and promote their application. The other founding members are NASA, the Russian Space Agency (RKA) and the Japanese Space Agency. The Chinese National Space Administration joined the group in 1995.

At the IADC's most recent meeting, another three members – CNES (France), BNSC (UK) and ISRO (India) – were admitted, bringing the total number of members to eight. That meeting, the IADC's 13th, was held at ESOC in late February with approximately 65 participants in attendance. As a result, several joint activities are being pursued to improve the knowledge of the debris environment in low Earth orbit and the geostationary orbit. The group will also prepare a common database of all space objects. One option is to prepare an extended version of ESOC's current DISCOS database as a preliminary step.

Space Education for a Changing World

The International Space University (ISU) is continuing to expand. It now offers two professional development programmes: the original Summer Session and a new Master of Space Studies programme. It has also recently added a continuing education programme, offering short courses or workshops on topical subjects.

These programmes are designed to respond to the educational needs and the increasing and evolving demands of the space sector in a rapidly changing world.

Summer Sessions
The Summer Session is held annually. It is an intensive 10-week programme that covers many space-related disciplines, taught from an international point of view. It is held at a different educational or research institute each year.

The Summer Sessions have been offered since 1988 and some 1000 alumni from 60 countries are now working around the world. Students have included Jim Newman (Class of 1989), now a NASA astronaut, who flew on the STS-51 mission in 1993, and Taber MacCallum (Class of 1988), who spent a year living in the 'Biosphere', a highly-publicised simulation of the Earth's ecosystem. A total of 34 alumni are also currently with ESA.

The next session will be held this summer, from 1 July to 6 September, in Vienna, Austria.

Master of Space Studies programme
The Master of Space Studies programme is an 11-month, post-graduate course aimed at participants ranging from young graduates to experienced professionals wishing to further their space-oriented education. It provides a new inter-disciplinary, international and intercultural educational experience.

The programme was launched last September and the first class (approximately 35 students) is expected to graduate this summer. The course is held at ISU's permanent campus in Strasbourg.

Continuing professional development programme
The ISU has also just recently launched a continuing education programme for professionals. It consists of short courses (typically one to five days), workshops and forums to help those interested in keeping up-to-date on new areas in the space field, or those joining the space field from another area. Sessions will be held at different locations around the world.

Further information on ISU can be found on the World Wide Web at:

http://www.isunet.edu/

Further Educational Opportunities: The Alpbach Summer School

The Summer School Alpbach is again offering young European scientists and engineers the opportunity to delve further into space-related studies under the guidance of experts in the field. This year, the course will focus on the theme 'Mission to the Moon: Science of the Moon, Science from the Moon'.

The lunar programme requires a long-term vision, but could be a catalyst for Europe's further development in a number of high-technology fields. Through lectures given by highly experienced scientists and engineers, and workshops, participants will examine the Moon's potential as a scientific outpost and as a natural 'space station'.

The Summer School is jointly organised by the Austrian Federal Ministry of Science, Research and the Arts, and the Austrian Space Agency (ASA), and is co-sponsored by ESA. This year's course is also being funded by the European Space Science Committee of the European Science Foundation. As usual, it will be held in Alpbach, a small village in the Austrian Alps, 60 km from Innsbruck, and 150 km from Munich.

The annual courses are open to graduate students and to young scientists and engineers from ESA Member States. For additional information, contact:

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Austrian Space Agency
Garnisongrasse 7
A-1090 Vienna
Austria

Tel: (43)1.403817712
Fax: (43)1.4058228

ESOC Monitors Re-entering Spacecraft

Two spacecraft recently caught the world's attention, but not in the usual way. The Russian Kosmos 398 and the Chinese FSW 1-5 (or China 40) re-entered the atmosphere, and it was not known whether fragments, or indeed the whole spacecraft in the case of FSW 1-5, would reach the Earth's surface. Such uncontrolled re-entries pose a potential risk to the population in the area covered by the object's orbit.

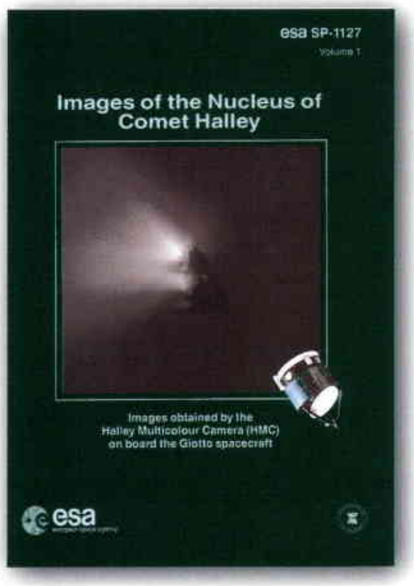
ESOC's Mission Analysis Section monitored both re-entries, as it does routinely for space debris. Using basic orbit information obtained by US and Russian space surveillance systems and data modelling, the group is able to predict the time and location of re-entry. ESOC then informs ESA's Member States of the status of the hazard.

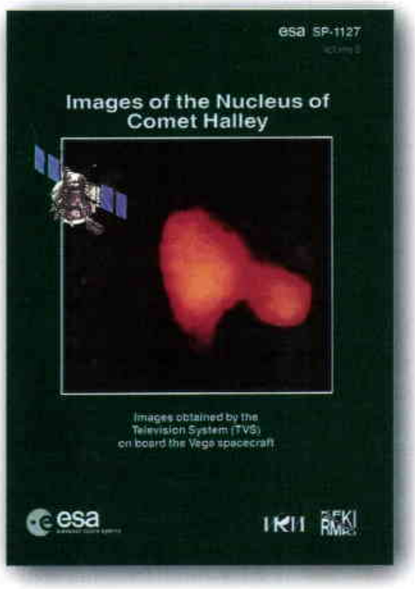
Kosmos 398 was launched in February 1971 as part of the Soviet manned lunar programme. Of the satellite's initial mass of about 7 tons, approxiamtely 2.5 tons were still in orbit when the spacecraft re-entered over the South Atlantic in December. Based on infrared observations made from space, it appears that the fragments of Kosmos 398 fell into the Atlantic Ocean.

The Chinese spacecraft FSW 1-5 (Fanhui Shi Weixing) was launched in October 1993 into an orbit with an altitude of 250 km. Instead of returning to Earth after 10 days, the re-entry capsule was erroneously inserted into a higher orbit. It re-entered on 12 March, also over the South Atlantic, falling in a tumbling motion which rendered its protective heat shield ineffective. Consequently, only a few fragments of the spacecraft reached the ocean surface.

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 Order Form at the back of this issue.

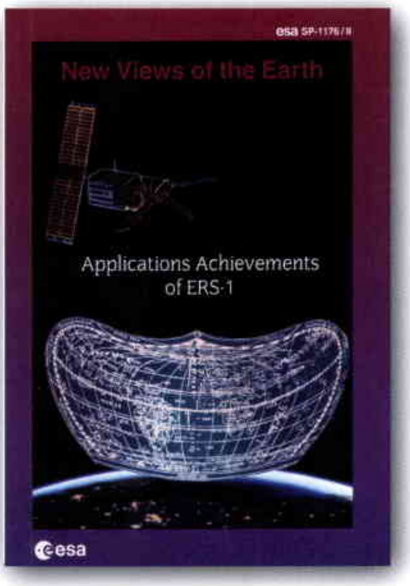




ESA Special Publications

ATLASES OF IMAGES OF THE NUCLEUS OF COMET HALLEY (MARCH 1996)
VOL. 1 - KELLER H.U. ET AL.
VOL. 2 - SZEGO K. ET AL.
ESA SP-1127 (2 VOLS.), 252 PP & 255 PP
PRICE: 100 DFL

NEW VIEWS OF THE EARTH: APPLICATIONS ACHIEVEMENTS OF ERS-1 (FEBRUARY 1996)
ESYS LTD. (ED. T.D. GUYENNE)
ESA SP-1176/II // 131 PP
PRICE: 70 DFL



MERIS, THE MEDIUM-RESOLUTION IMAGING SPECTROMETER - PARTS A & B (FEBRUARY 1996)
RAST M. (ED. M. PERRY)
ESA SP-1184 // 63 PP
PRICE: 50 DFL

THE NINE CANDIDATE EARTH EXPLORER MISSIONS: REPORTS FOR ASSESSMENT (APRIL 1996)

VOL. 1: GRAVITY FIELD AND STEADY-STATE OCEAN CIRCULATION MISSION

VOL. 2: LAND-SURFACE PROCESSES AND INTERACTIONS MISSION

VOL. 3: EARTH RADIATION MISSION

VOL. 4: ATMOSPHERIC DYNAMICS MISSION

VOL. 5: MAGNETOMETRY MISSION

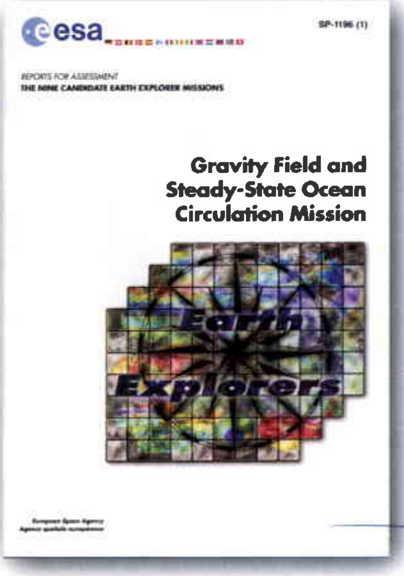
VOL. 6: ATMOSPHERIC CHEMISTRY MISSION

VOL. 7: ATMOSPHERIC PROFILING MISSION

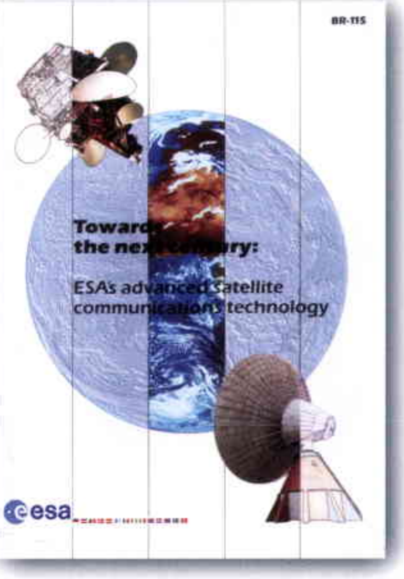
VOL. 8: PRECIPITATION MISSION

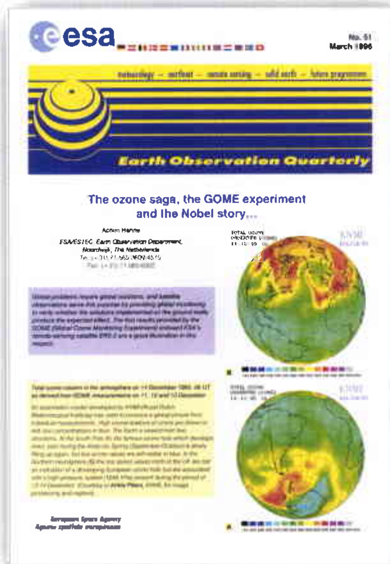
VOL. 9: TOPOGRAPHY MISSION

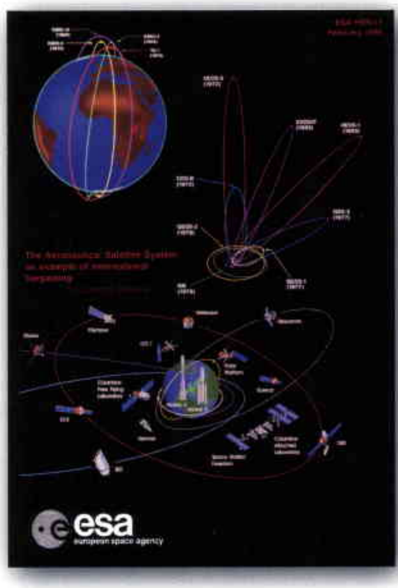
READINGS C.J. & REYNOLDS M.L. (ED. T.D. GUYENNE)
ESA SP-1196 // 683 PP
PRICE : 100 DFL



ARIANE-5 GROUND FACILITIES/ INSTALLATIONS SOL (BILINGUAL: ENGLISH/FRENCH) (MARCH 1996)
ARIANE DEPT., ESA (ED. T.D. GUYENNE)
ESA SP-1197 // 362 PP
NOT FOR SALE







PROCEEDINGS OF THE SECOND ERS APPLICATIONS WORKSHOP, LONDON (DECEMBER 1996)
GUYENNE T.D. (ED.)
ESA SP-383 // 499 PP
PRICE: 100 DFL

ESA Brochures

TOWARDS THE NEXT CENTURY: ESA's ADVANCED SATELLITE COMMUNICATIONS TECHNOLOGY (FEBRUARY 1996)
MAUROSCHAT A. (ED. C. MATTOK)
ESA BR-115 // 48 PP
PRICE 35 DFL

ESA Procedures, Standards & Specifications

GUIDE TO SOFTWARE PROJECT MANAGEMENT
ESA BOARD FOR SOFTWARE STANDARDISATION AND CONTROL (BSSC)
ESA PSS-05-06 ISSUE 1 // 84 + VIII
PRICE 50 DFL

ESA Newsletters

EARTH OBSERVATION QUARTERLY
NO. 51, MARCH 1996
ED. T.D. GUYENNE
NO CHARGE

PREPARING FOR THE FUTURE
VOLUME 6, NUMBER 1
ED. M. PERRY
NO CHARGE

REACHING FOR THE SKIES
NO. 15, JANUARY 1996
ED. T.D GUYENNE
NO CHARGE

ESA Scientific and Technical Reports

VERY LARGE SCALE INTEGRATION (VLSI) FOR DIGITAL SIGNAL PROCESSING (DSP) IN SPACE (SEPTEMBER 1995)
HOLLREISER M.
ESA STR-239 // 35 PP
PRICE: 35 DFL

ESA History Series

THE AERONAUTICAL SATELLITE SYSTEM: AN EXAMPLE OF INTERNATIONAL BARGAINING (FEBRUARY 1996)
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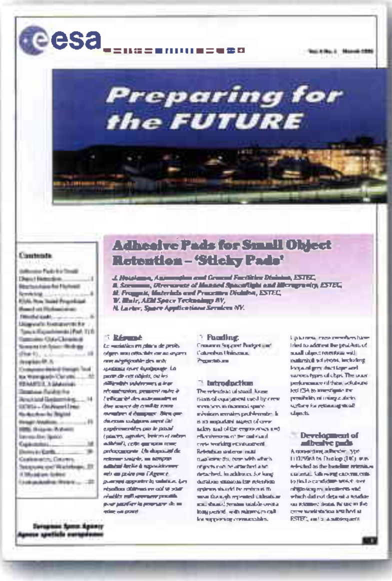

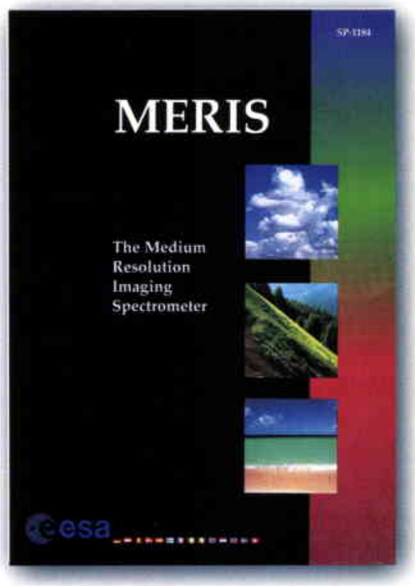

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